Laboratórios de Pesquisa em Refrigeração e Termofísica
Research Laboratories for Emerging Technologies in Cooling and Thermophysics

A NTU-Based Model to Estimate Suction Superheating in Scroll Compressors

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22nd International Compressor Engineering Conference

Summary

1. Introduction/Motivation

2. Compression process model

3. Thermal model

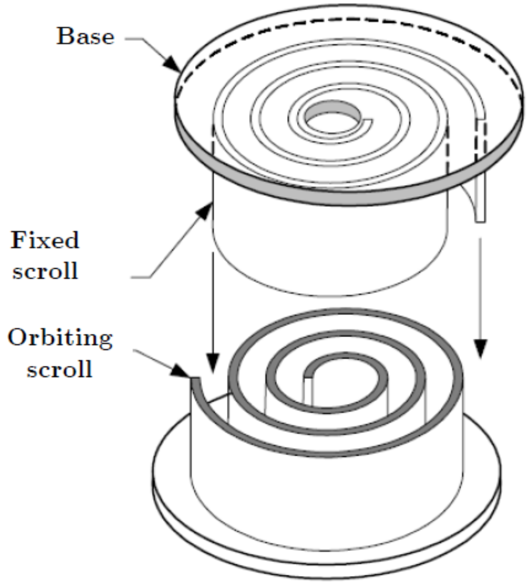
4. Results

5. Conclusions

Scroll compressors

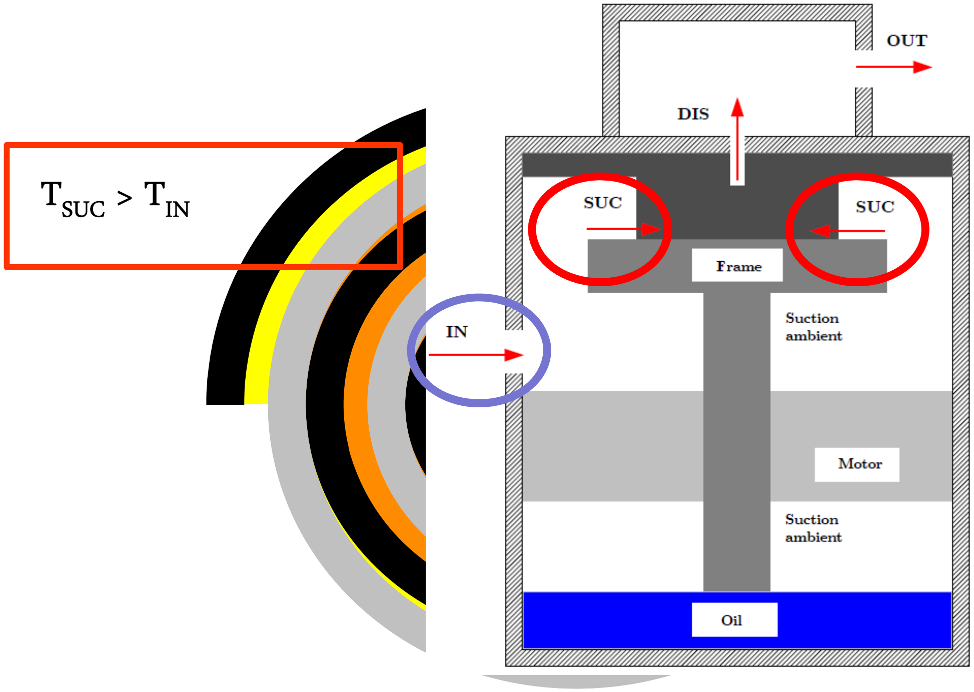
- **Compression process:**
  - Performed by two identical scrolls;
  - Occurs from outer to central region;
  - Continuous;
  - Few moving parts;

- **Important characteristics:**
  - Low noise and vibration;
  - High efficiency and reliability;
  - Easy modulation of capacity;



Heat transfer inefficiencies

- **Loss of performance:**
  - Suction superheating;
  - Compression chamber superheating;
- **Reliability:**
  - Discharge temperature;



Objectives

<u>Develop</u> a model to predict suction superheating in scroll compressors:

- Couple to a compression process model;

<u>Evaluate</u> its versatility:

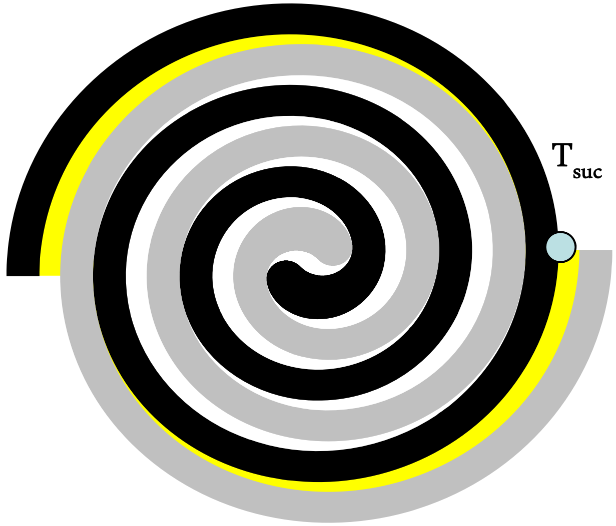
- Test the model in two compressor with different refrigerants;

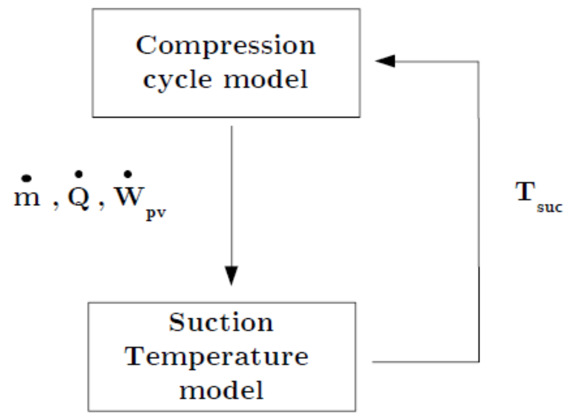
Compression process model

- **Developed by Pereira (2012);**

- **Main characteristics:**
  - Calculation of geometric parameters;
  - Transient lumped conservation equations;
  - Leakage and heat transfer correlations were developed;
  - Requires a certain number of cycles to achieve convergence;

- **Interaction with thermal model**
  - Receives T_{suc};
  - Returns mass flux, heat transfer and indicated power;





Thermal model

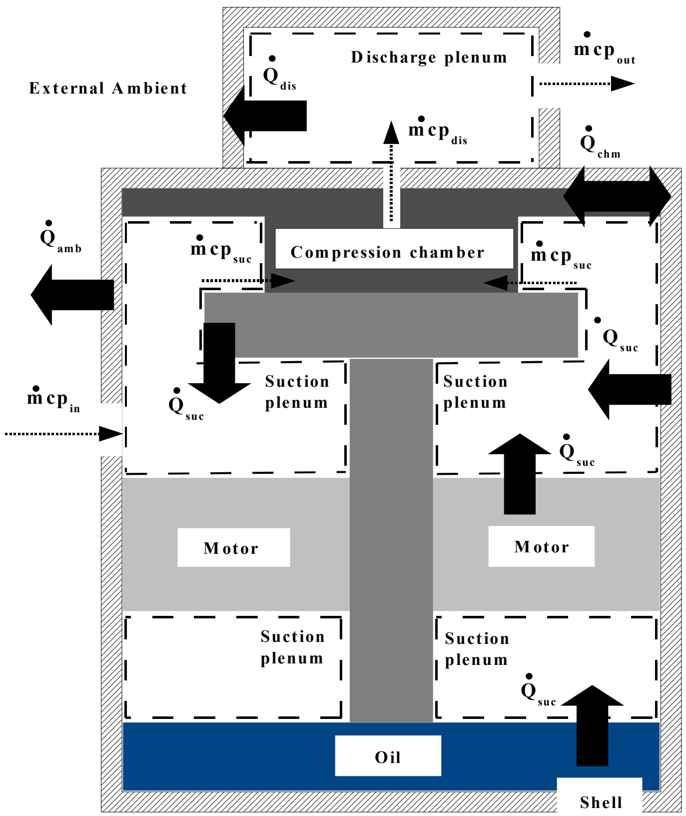
- **Existing thermal models:**
  - Usually experimentally calibrated;
  - Only applicable to specific compressors and operating conditions;
  - Cannot be used as project tools;

- **This work proposes:**
  - Simplified thermal model;
  - No experimental calibration;
  - Based on Winandy et al. (2002) model;

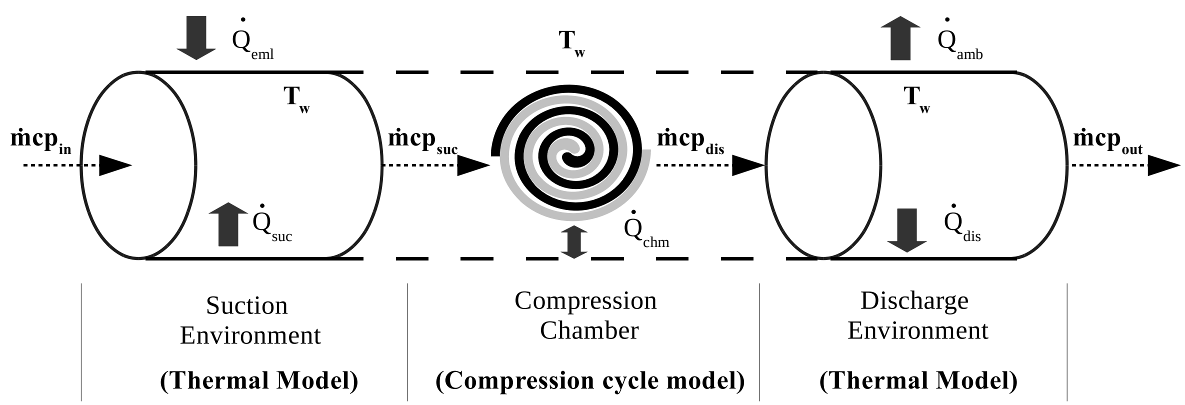
- **Winandy et al. (2002):**
  - Sequence of steps to represent the phenomena inside the compressor;
  - Employs an isothermal fictitious surface;
  - Uses experimental data for calibration;
  - Was successfully used and improved by other authors (Cuevas et al., 2009 and Duprez et al., 2010);

Thermal model: simplification

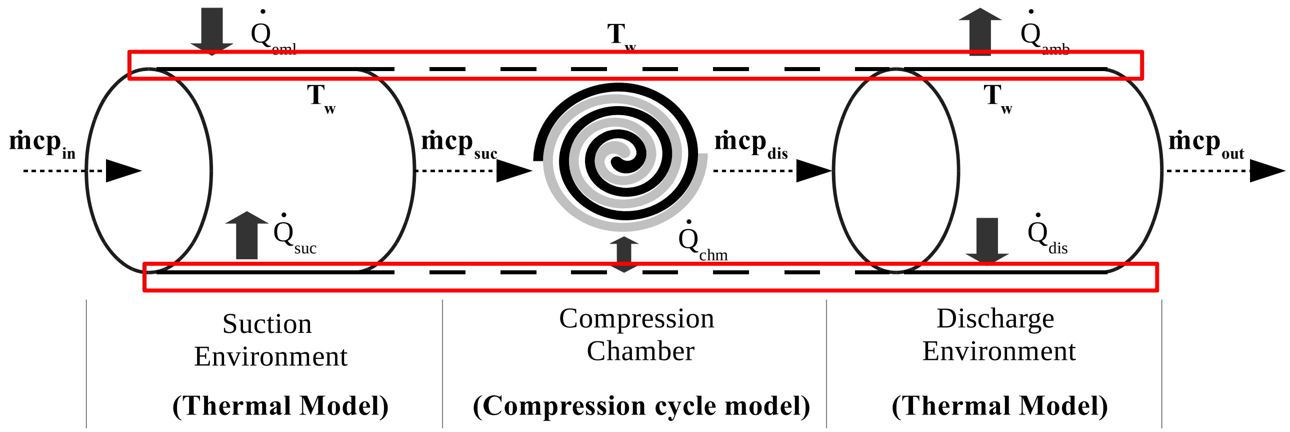
Real geometry



Simplified flow approach

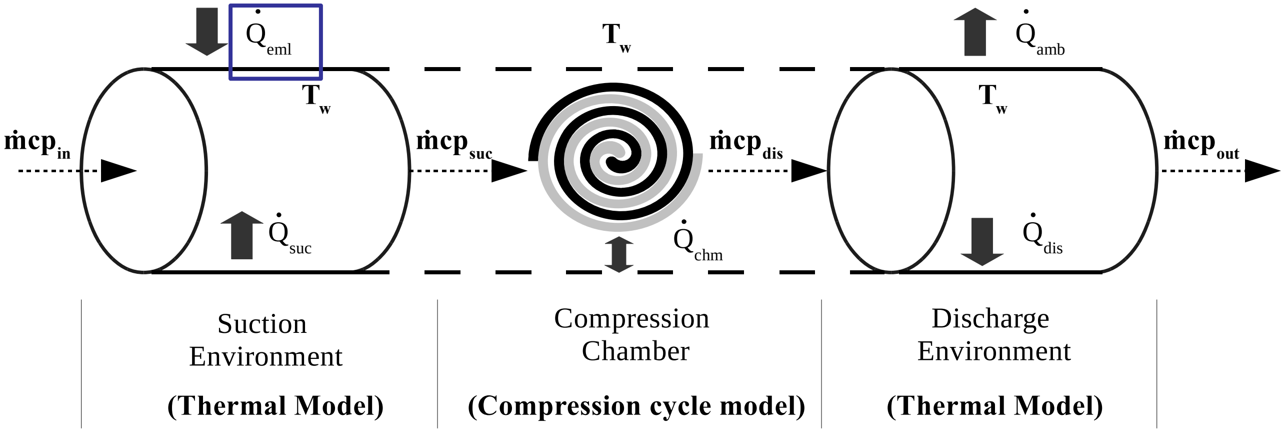


Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml}$$

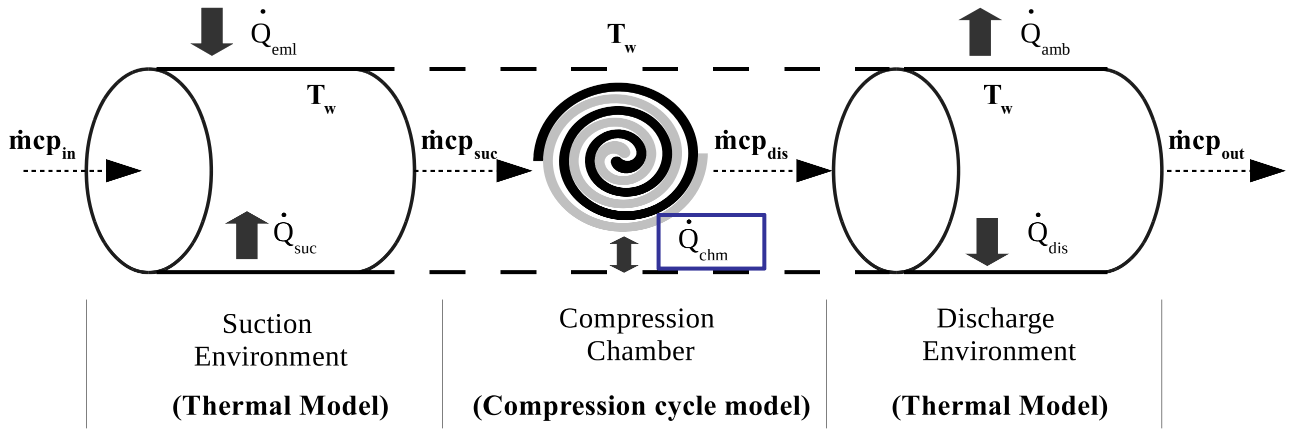
Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml}$$

$$\dot{Q}_{eml} = \frac{\dot{W}_{pv}}{\eta_{eml}} - \dot{W}_{pv}$$

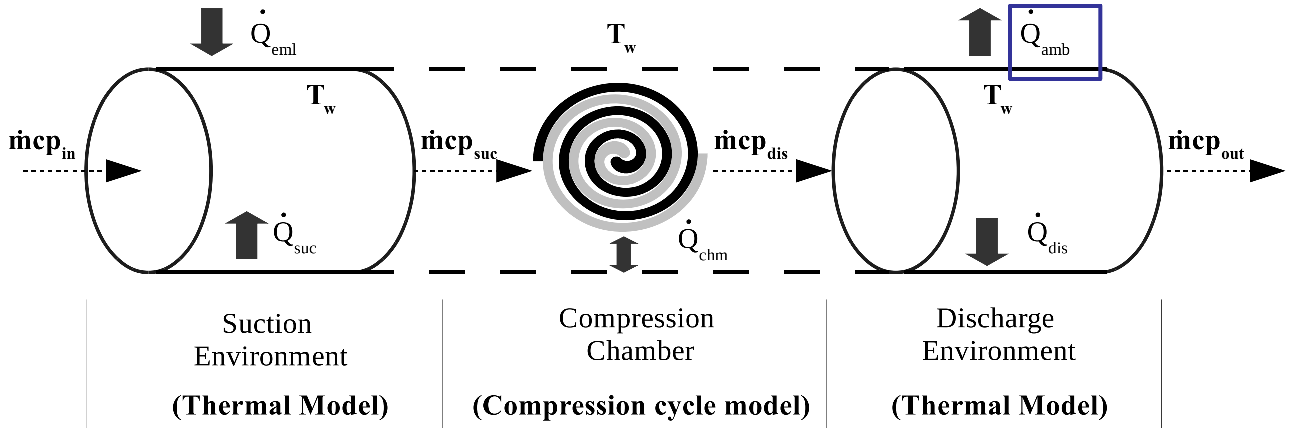
Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \boxed{\dot{Q}_{chm}} + \dot{Q}_{eml}$$

From compression process model

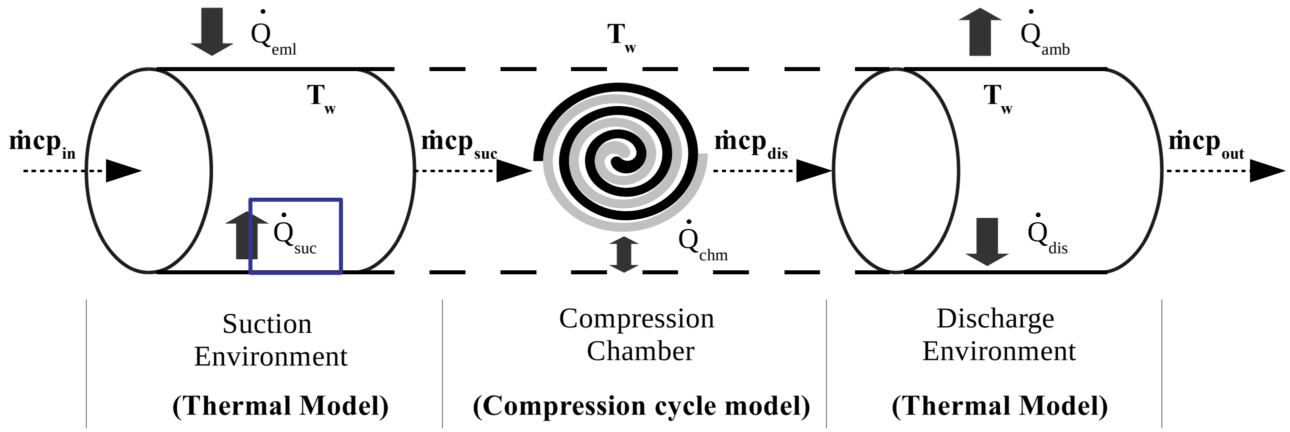
Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml}$$

$$\dot{Q}_{amb} = h_{amb} A_{cmp} (T_w - T_{amb})$$

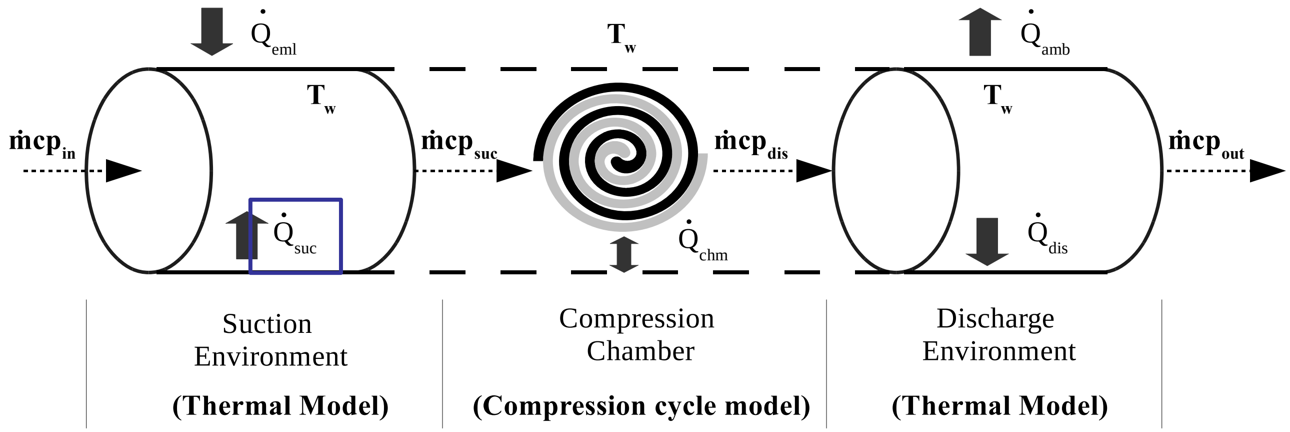
Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml}$$

$$\dot{Q}_{suc} = \varepsilon_{suc} \dot{m} c_P (T_w - T_{in})$$

Thermal model: equations



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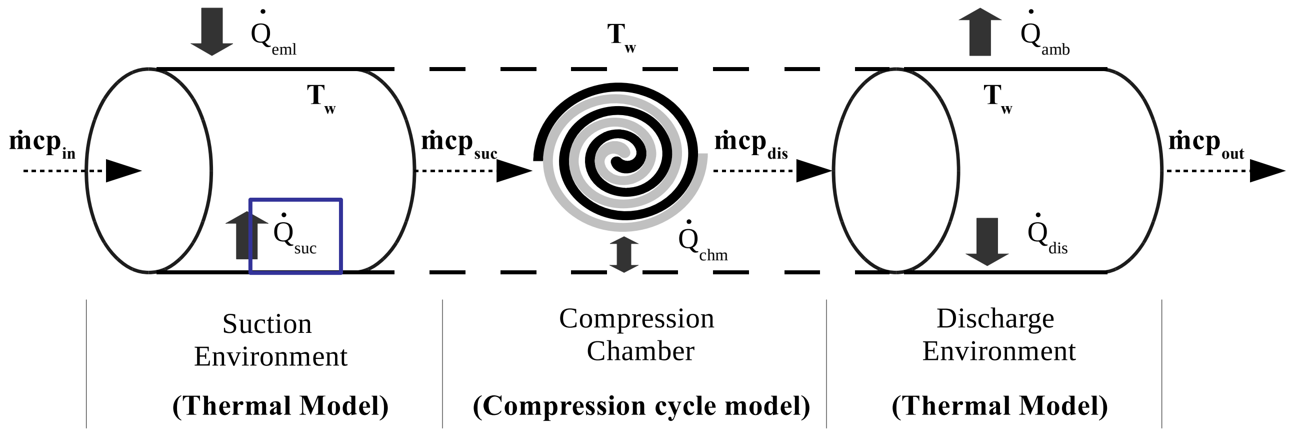
$$\dot{Q}_{suc} = \varepsilon_{suc} \dot{m} c_P (T_w - T_{in})$$

$$\varepsilon_{suc} = 1 - \exp(-h_{suc} A_{suc} / \dot{m} c_P)$$

Thermal model: equations



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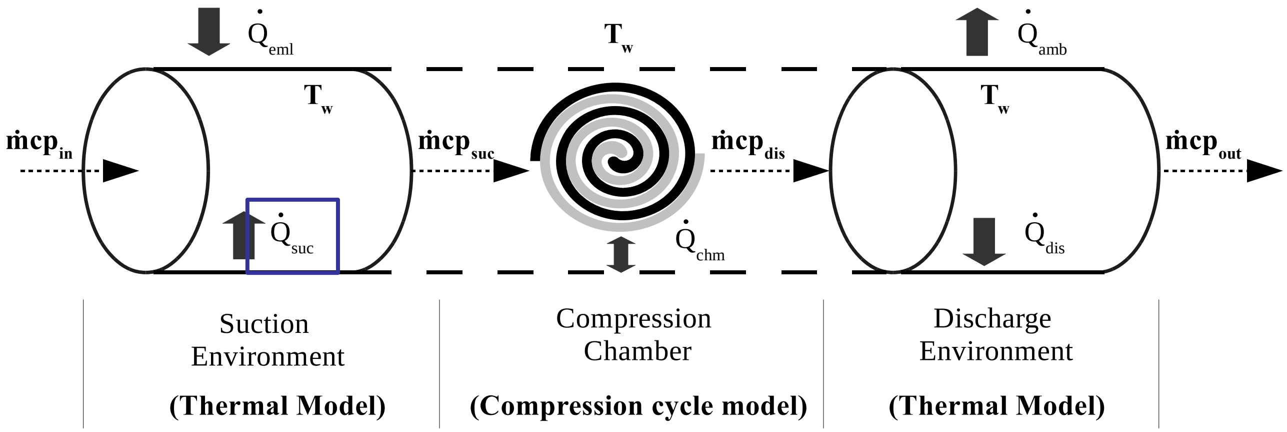
$$\dot{Q}_{suc} = \varepsilon_{suc} \dot{m} c_P (T_w - T_{in})$$

$$Nu_{suc} = \frac{h_{suc} D_{suc}}{k} = 0.023 \mathrm{Re}_{suc}^{0.8} \mathrm{Pr}^{0.4}$$

$$\varepsilon_{suc} = 1 - \exp(-h_{suc} A_{suc} / \dot{m} c_P)$$

Thermal model: equations



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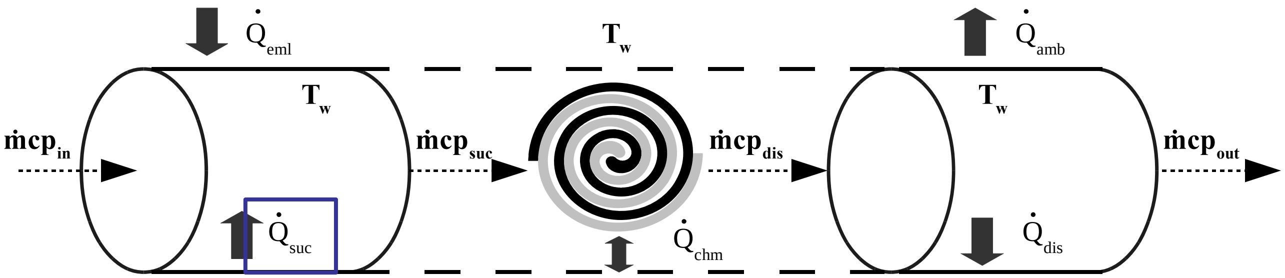
$$\mathrm{Re}_{suc} = \frac{4\dot{m}}{\pi D_{suc} \mu_{suc}}$$

Thermal model: equations



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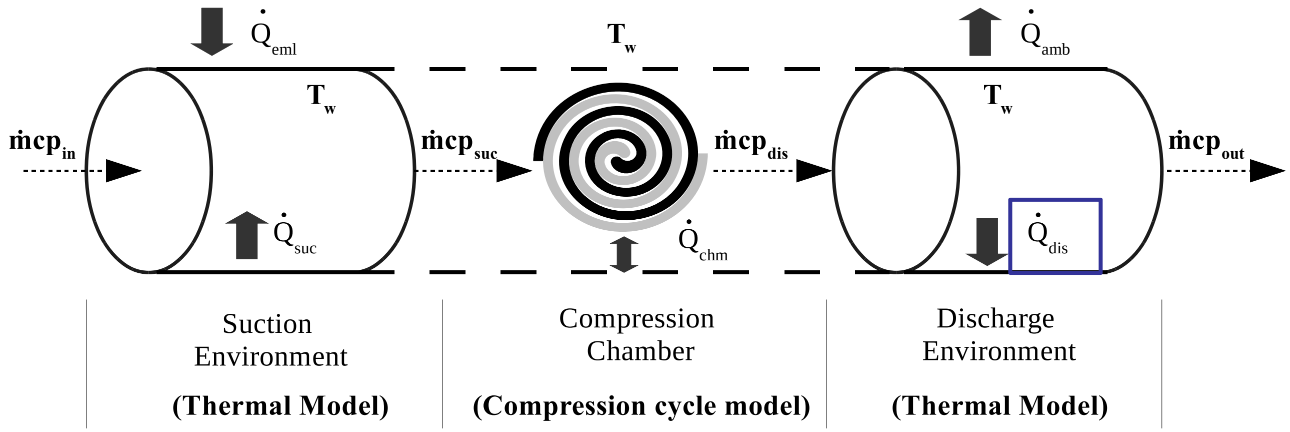
$$\mathrm{Re}_{suc} = \frac{4\dot{m}}{\pi D_{suc} \mu_{suc}} \qquad D_{suc} = \frac{4V_{suc}}{A_{suc}}$$

Thermal model: equations



$$\dot{Q}_{suc} + \dot{Q}_{amb} = \dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml}$$

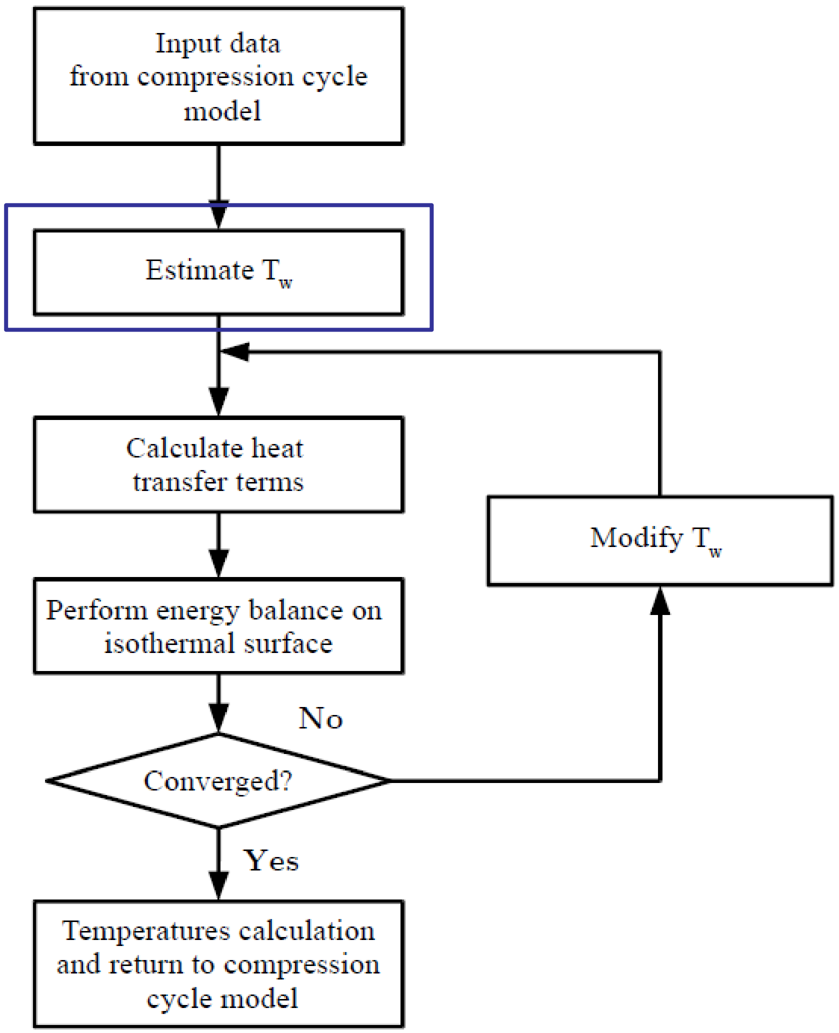
$$\dot{Q}_{dis} = \varepsilon_{dis} \dot{m} c_P (T_{dis} - T_w)$$

$$Nu_{dis} = \frac{h_{dis} D_{dis}}{k} = 0.023 \mathrm{Re}_{dis}^{0.8} \mathrm{Pr}^{0.3}$$

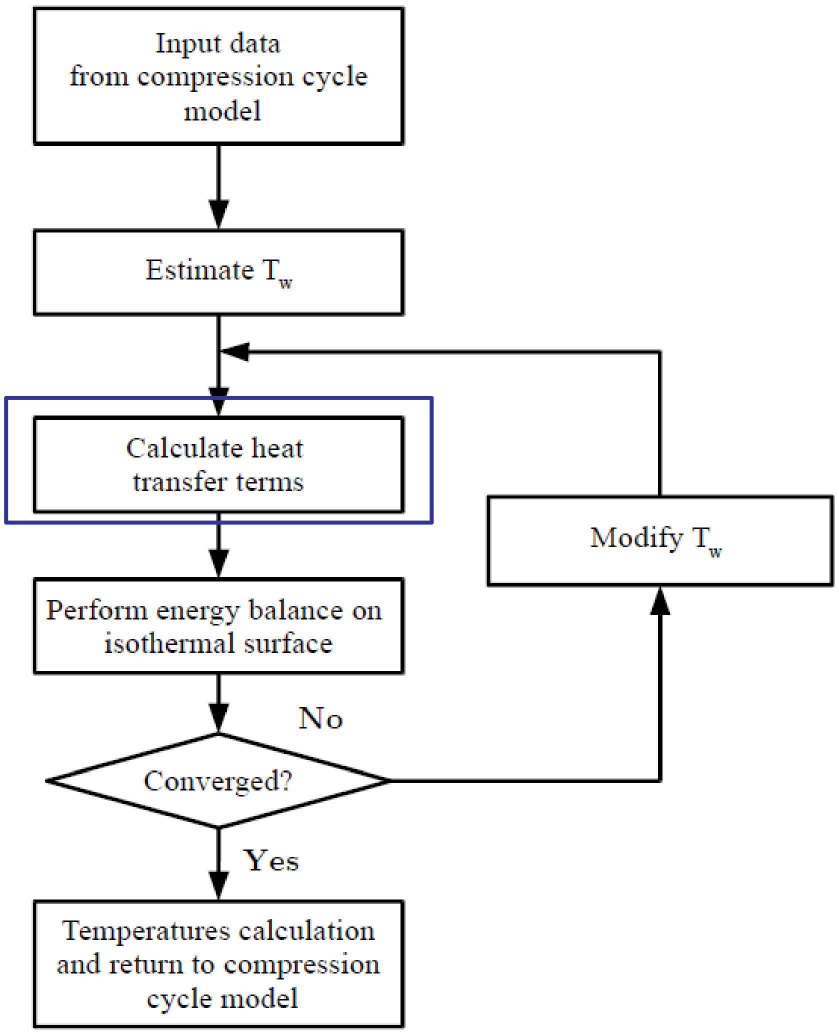
$$\varepsilon_{dis} = 1 - \exp(-h_{dis} A_{dis} / \dot{m} c_P)$$

$$\mathrm{Re}_{dis} = \frac{4\dot{m}}{\pi D_{dis} \mu_{dis}} \qquad D_{dis} = \frac{4V_{dis}}{A_{dis}}$$

Thermal model: chart



Thermal model: chart



$\dot{Q}_{suc}$

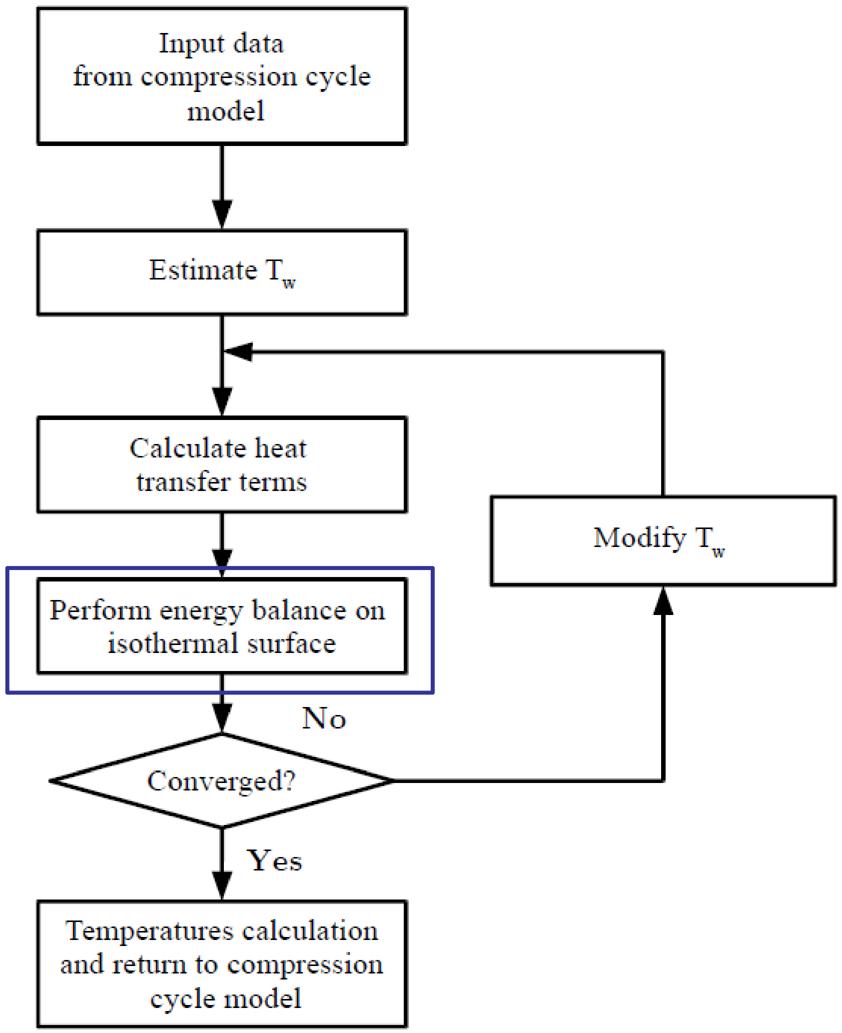
$\dot{Q}_{amb}$

$\dot{Q}_{dis}$

$\dot{Q}_{chm}$

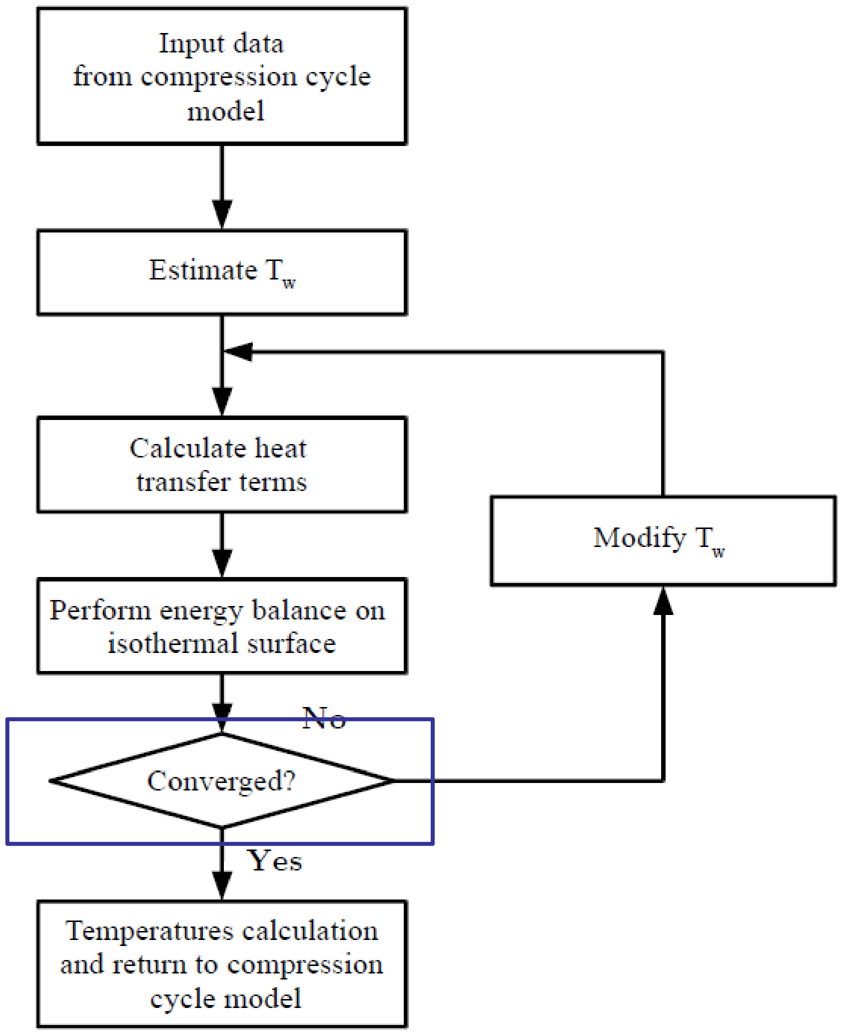
$\dot{Q}_{eml}$

Thermal model: chart



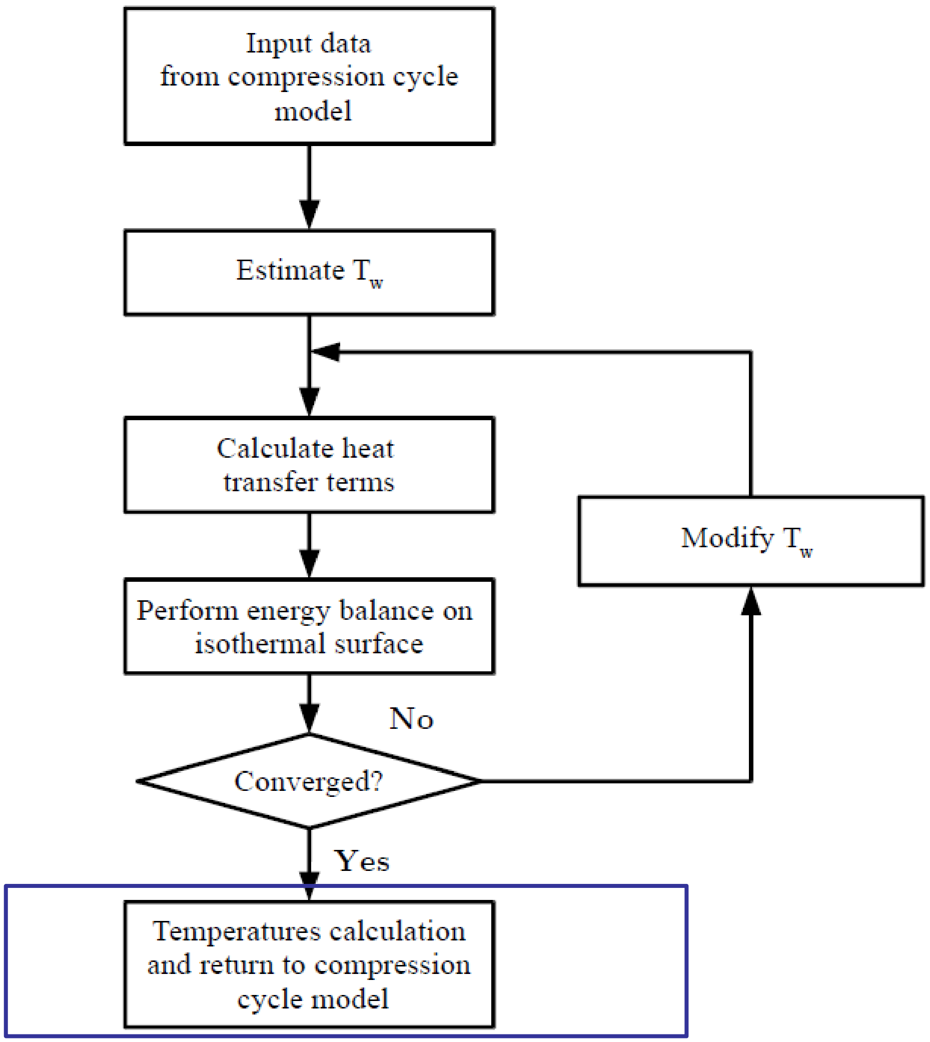
$$\sum \dot{Q} = \dot{Q}_{suc} + \dot{Q}_{amb} - (\dot{Q}_{dis} + \dot{Q}_{chm} + \dot{Q}_{eml})$$

Thermal model: chart



$$\sum \dot{Q} \leq \frac{0.01}{100} \dot{W}_{ele} \, ?$$

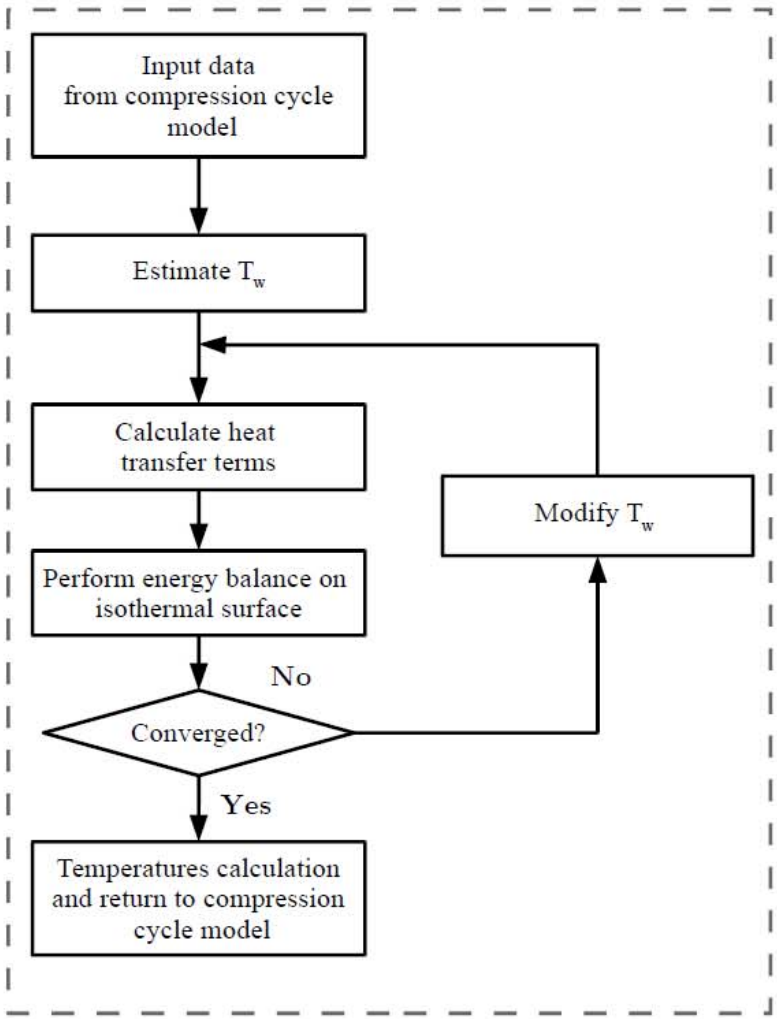
Thermal model: chart

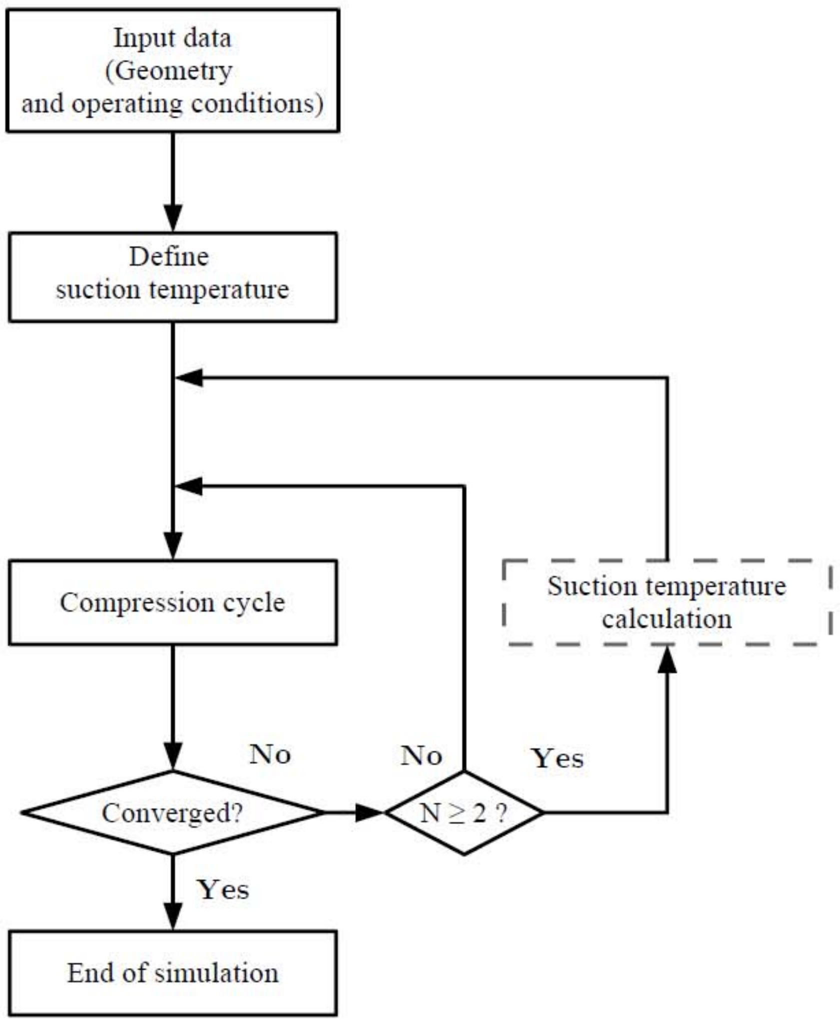


$$\dot{Q}_{suc} = \dot{m} c_P (T_{suc} - T_{ent})$$

$$\dot{Q}_{dis} = \dot{m} c_P (T_{dis} - T_{out})$$

Complete model solution





Results: compressors A and B

Compressor A

Speed	T_e	T_c	T_{in}	T_{suc} [°C]			T_{out} [°C]		
				Exp.	Num.	Error	Exp.	Num.	Error
8000	-27	42	35.6	77.9	76.0	-1.9	143.6	174.6	31.0
10000	-27	42	34.4	75.8	71.9	-3.9	143.0	169.7	26.7

Compressor B

Speed	Condition	T_e	T_c	T_{in}	T_{suc} [°C]			T_{out} [°C]		
					Exp.	Num.	Error	Exp.	Num.	Error
8000	AHRI-A	7.2	54.4	21.4	44.4	45.9	1.5	107.3	116.3	9.0
10000		7.2	54.4	20.7	44.0	47.3	3.3	109.2	118.5	9.3
8000	AHRI-D	-1.1	43.3	12.7	41.2	43.6	2.4	99.2	111.6	12.4
10000		-1.1	43.3	12.6	41.00	44.6	3.6	101.5	112.8	11.3
8000	AHRI-G	1.7	32.2	16.13	40.82	39.0	-1.8	83.5	89.6	6.1
10000		1.7	32.2	15.32	40.46	41.5	1.0	86.3	93.4	7.1

Results: compressors A and B

Compressor A

Speed	T_e	T_c	T_{in}	T_{suc} [°C]			T_{out} [°C]		
				Exp.	Num.	Error	Exp.	Num.	Error
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10000	-27	42	34.4	75.8	71.9	-3.9	143.0	169.7	26.7

Compressor B

Speed	Condition	T_e	T_c	T_{in}	T_{suc} [°C]			T_{out} [°C]		
					Exp.	Num.	Error	Exp.	Num.	Error
8000	AHRI-A	7.2	54.4	21.4	44.4	45.9	1.5	107.3	116.3	9.0
10000		7.2	54.4	20.7	44.0	47.3	3.3	109.2	118.5	9.3
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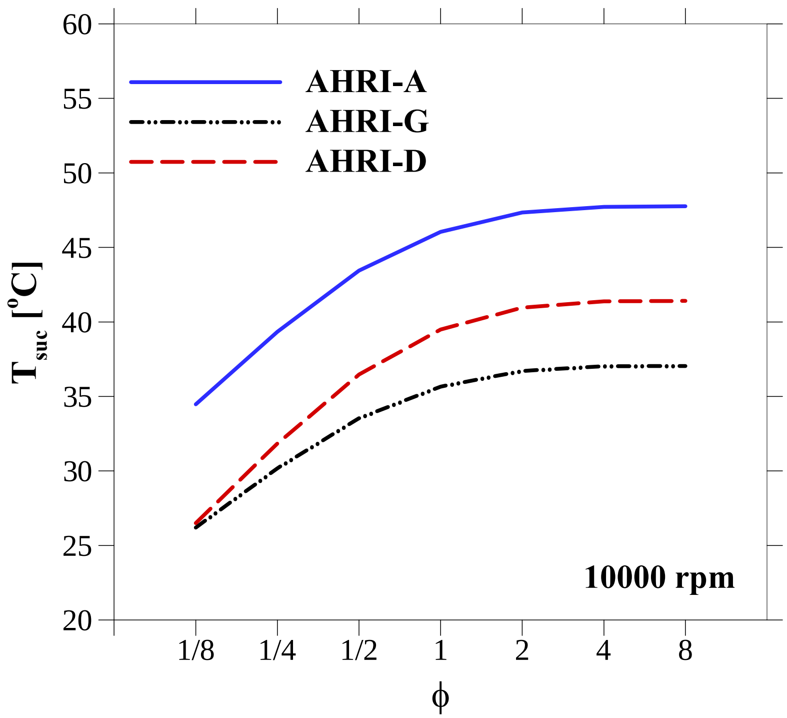
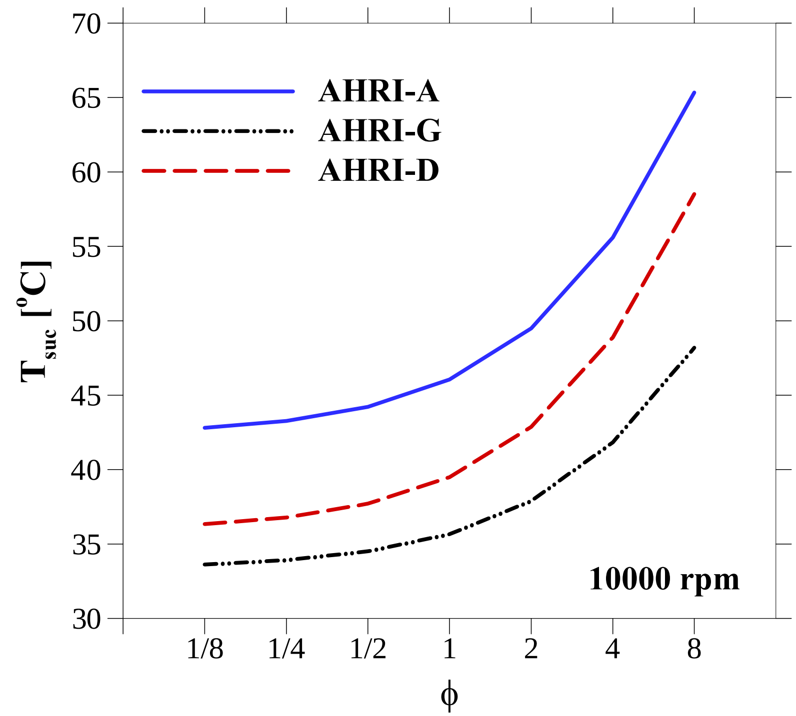
Results: h_{suc} and h_{dis} variation

h_{suc}

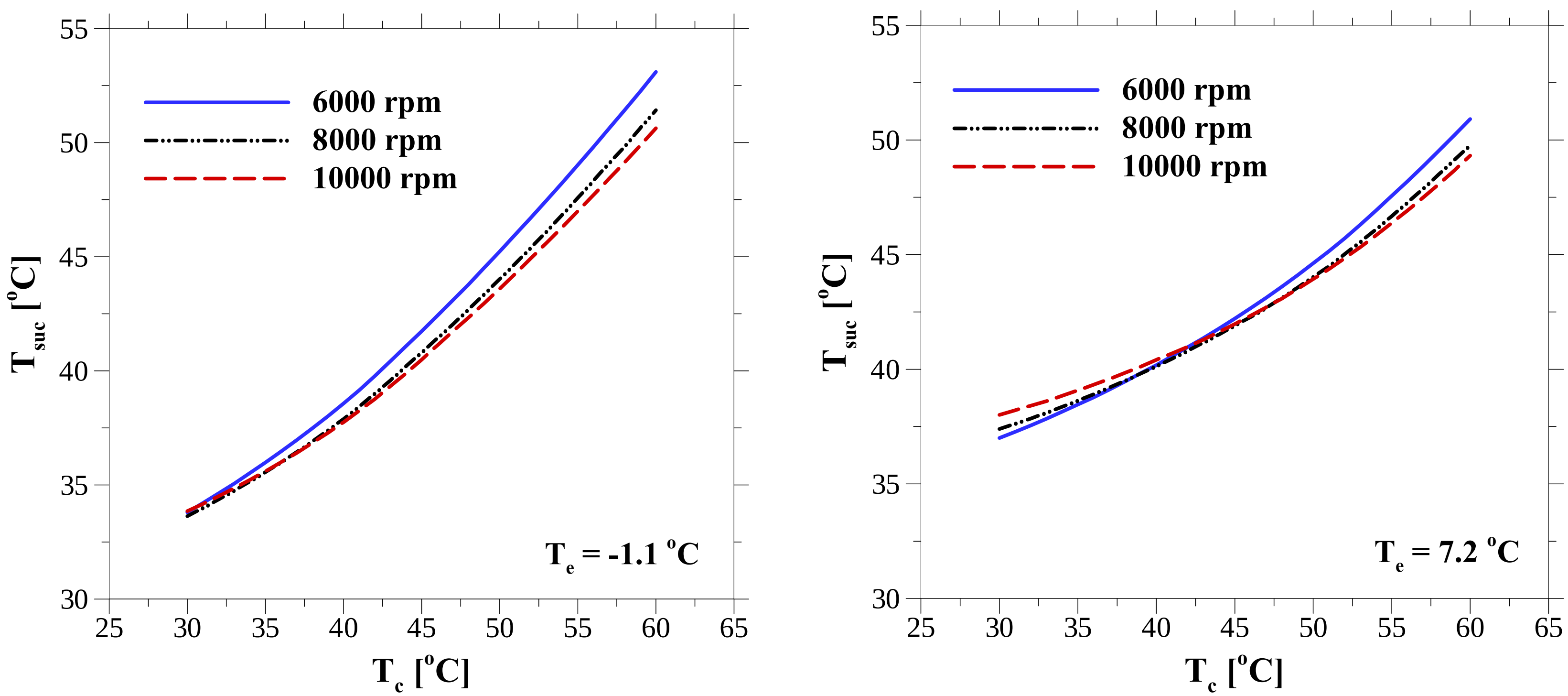


h_{dis}



- When h_{suc} increases, suction temperature also increases.
- h_{dis} influences more the suction temperature;

Results: operating conditions variation



- Suction temperature increase with pressure ratio is more noticed at lower evaporation temperatures and lower speeds;

Conclusions

- **Coupled solution:**
  - Allows a comprehensive simulation of compressor performance;
  - Simple thermal model;
  - No experimental calibration;

- **Two different compressors;**
  - Good estimation for suction temperature;
  - Not so good estimation for outlet temperature;
  - More heat transfer coefficients should be tested;

- **Sensitivity analysis:**
  - Physically consistent behavior;
  - Allows the estimation of efficiencies;

Acknowledgements

The present investigation is part of a cooperation agreement between the Federal University of Santa Catarina (UFSC) and EMBRACO.

Support from the Brazilian Funding Agencies FINEP and CAPES is also appreciated.

Thank you!

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