Laboratórios de Pesquisa em Refrigeração e Termofísica

Research Laboratories for Emerging Technologies in Cooling and Thermophysics

Development of a Lumped-Parameter Model for Hermetic Reciprocating Compressor with Thermal-Electrical Coupling

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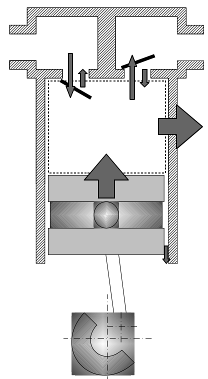
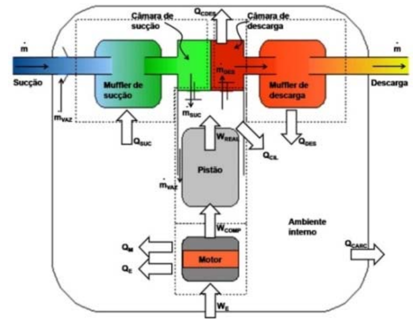
INTRODUCTION

Different phenomena take place inside hermetic compressors:

- thermodynamic,
- heat transfer,
- electromagnetic processes…





Therefore, **multi-physics** modeling is required for comprehensive simulations.

An electrical motor model allows one to predict the motor parameters effect on both heat transfer and thermodynamic cycle.

INTRODUCTION

OBJECTIVE: To propose a coupled comprehensive model for hermetic reciprocating compressors simulation.

The coupled model is composed by three sub-models:

- A **thermodynamic model** for the compression cycle;
- A **thermal model** for prediction of compressor components temperatures;
- An **electrical model** for prediction of a single-phase induction motor performance (efficiency, motor losses and torque).

THERMODYNAMIC MODEL

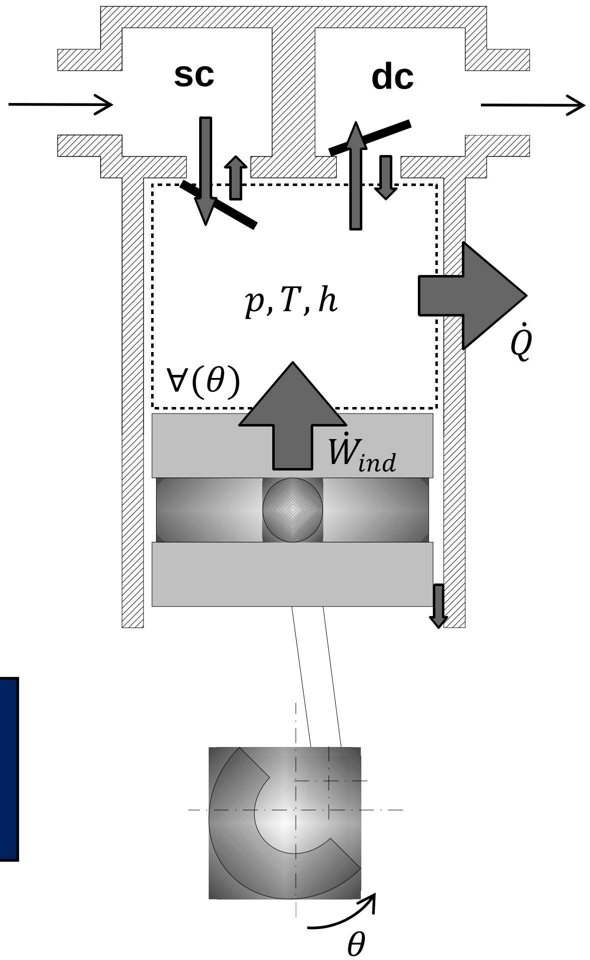
The thermodynamic model (Todescat *et al.* 1992) is given by the combination of four major models to compute:

i. Compression chamber volume as a function of the crank angle;

ii. Instantaneous thermodynamic properties inside the compression chamber;

iii. Valves dynamics;

iv. Mass flow rates.



Indicated power

$$\dot{W}_{ind} = -f \oint p d\forall$$

Shaft power

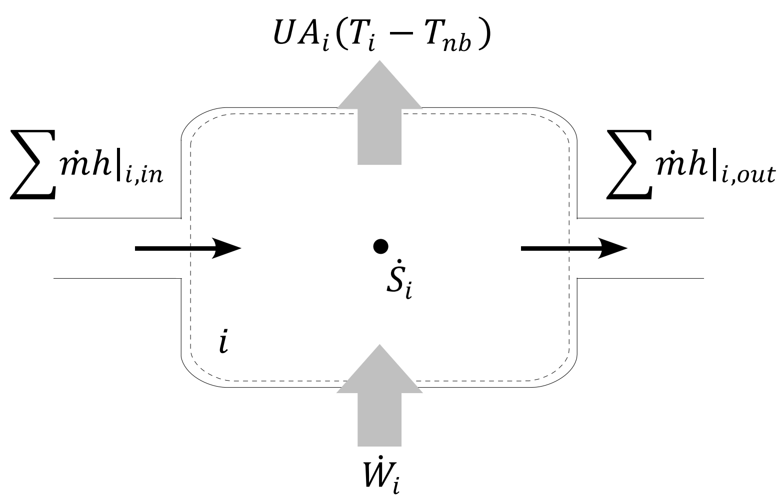
$$\dot{W}_{shaft} = \dot{W}_{ind} + \dot{W}_b$$

THERMAL MODEL

The thermal model is similar to Fagotti *et al.* (1994), given by the application of the energy equation to lumped elements:

$$\dot{Q}_i - \dot{W}_i = \sum \dot{m}h|_{i,in} - \sum \dot{m}h|_{i,out}$$

$$\dot{Q}_i = UA_i(T_i - T_{nb}) + \dot{S}_i$$

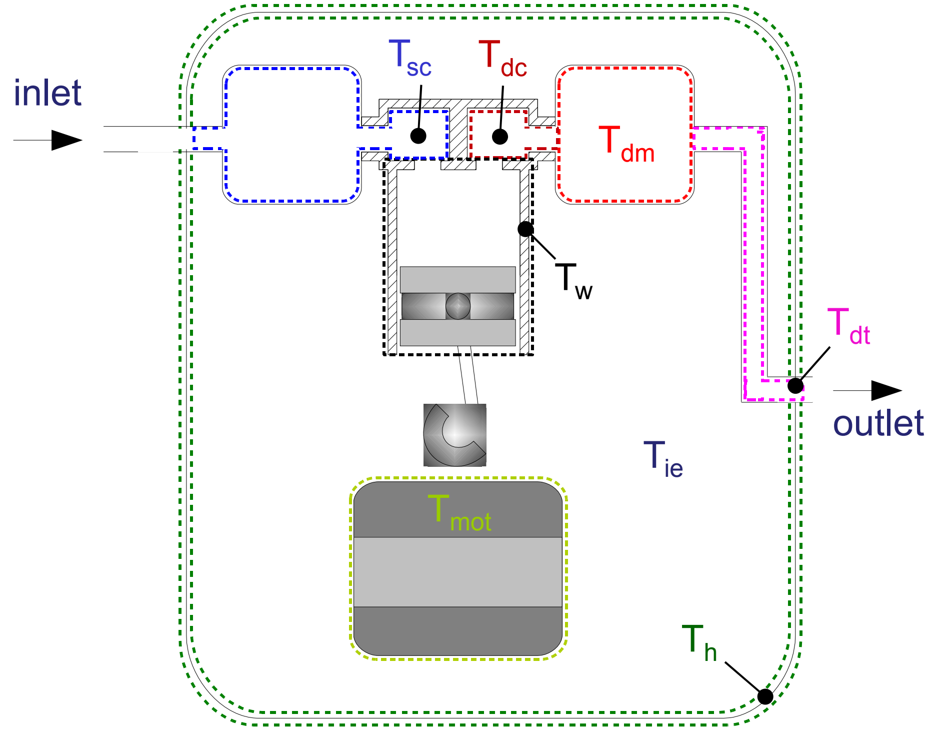


UAs are obtained from a set of temperature measurements (ASHRAE LBP -23.3°C/54.4°C; 32.0°C/32.0°C).

THERMAL MODEL

The compressor lumped elements are:

1. Suction muffler (T_{sc})
2. Compression chamber (T_w)
3. Discharge chamber (T_{dc})
4. Discharge muffler (T_{dm})
5. Discharge tube (T_{dt})
6. Motor (T_{mot})
7. Housing (T_h)
8. Internal Environment (T_{ie})

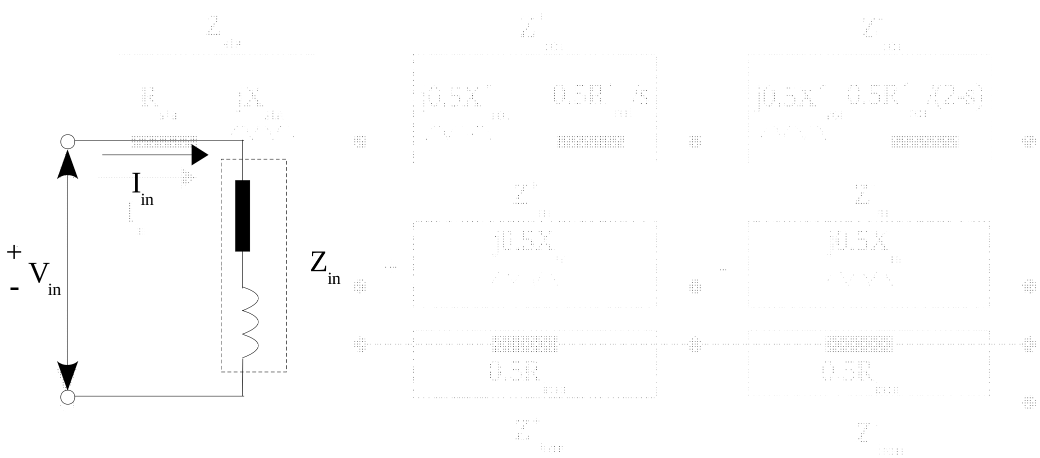


A non-linear equation system is solved to obtain the compressor temperatures.

ELECTRICAL MODEL

The electrical model is based on the **equivalent circuit method** (Fitzgerald *et al.* 2006; Hrabovcova *et al.* 2010) of a single-phase induction motor.

Rotor, magnetizing and core loss branches are divided into forward (+) and backward (-) loops, according to the **rotating magnetic field theory**.



Slip ratio

$$s = 1 - \frac{\omega}{\omega_s}$$

Input current

$$I_{in} = \frac{V_{in}}{Z_{in}}$$

Electrical parameters were supplied by the compressor manufacturer.

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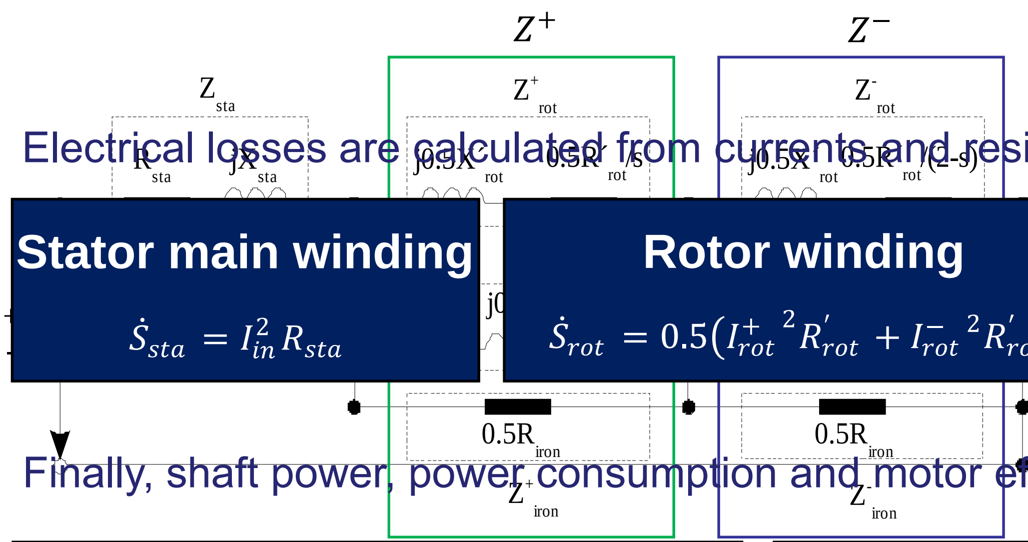


+ Currents

- Currents

Currents are calculated in each branch.

Electrical losses are calculated from currents and resistances:

Stator main winding

$$\dot{S}_{sta} = I_{in}^2 R_{sta}$$

Rotor winding

$$\dot{S}_{rot} = 0.5\left(I_{rot}^{+\,2} R'_{rot} + I_{rot}^{-\,2} R'_{rot}\right)$$

Stator core

$$\dot{S}_{iron} = 0.5\left(I_{iron}^{+\,2} R_{iron} + I_{iron}^{-\,2} R_{iron}\right)$$

Finally, shaft power, power consumption and motor efficiency are computed:

Shaft power

$$\dot{W}_{shaft} = \frac{(1-s)}{2}\left(I_{rot}^{+\,2}\frac{R'_{rot}}{s} + I_{rot}^{-\,2}\frac{R'_{rot}}{2-s}\right)$$

Power consumption

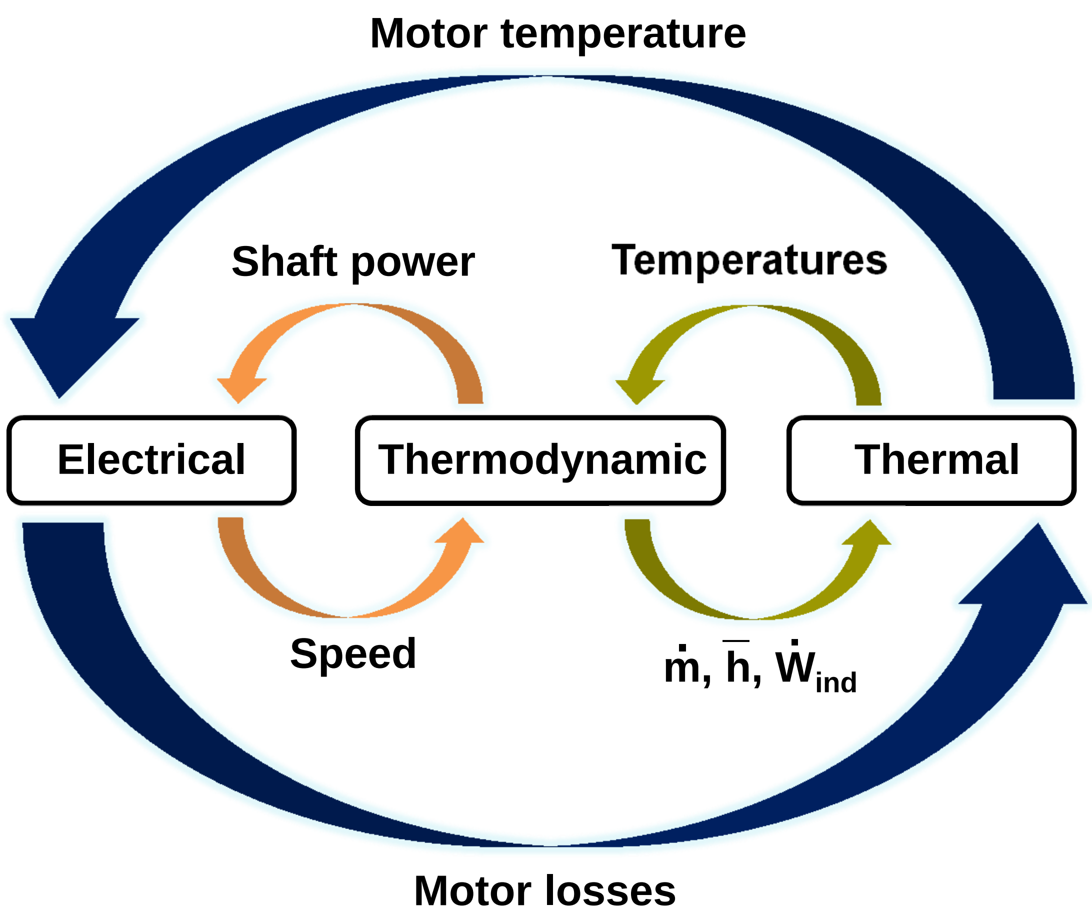
$$\dot{W}_{in} = \dot{W}_{shaft} + \sum \dot{S}$$

Motor efficiency

$$\eta_{mot} = \frac{\dot{W}_{shaft}}{\dot{W}_{in}}$$

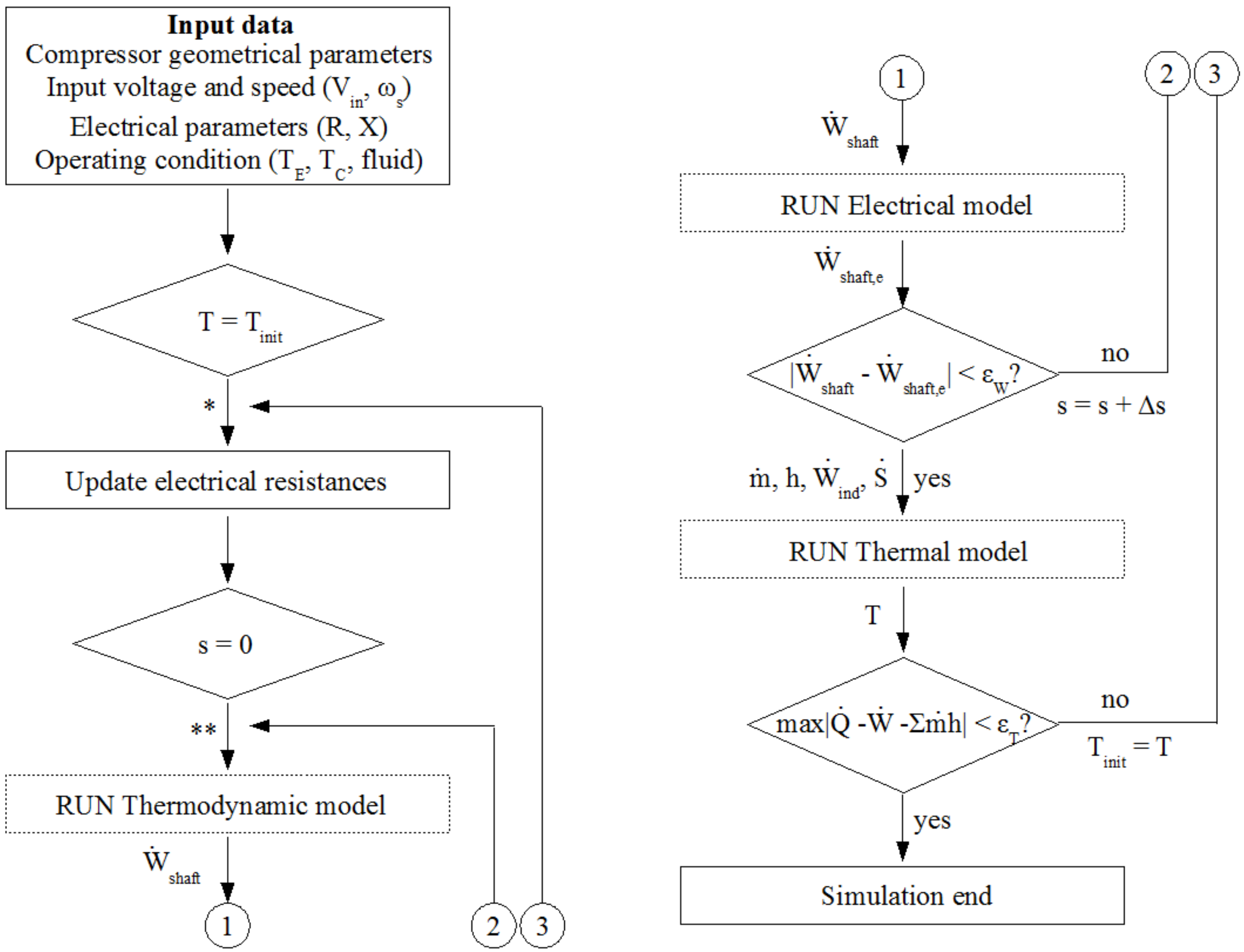
SOLUTION PROCEDURE

Interaction between models:



SOLUTION PROCEDURE

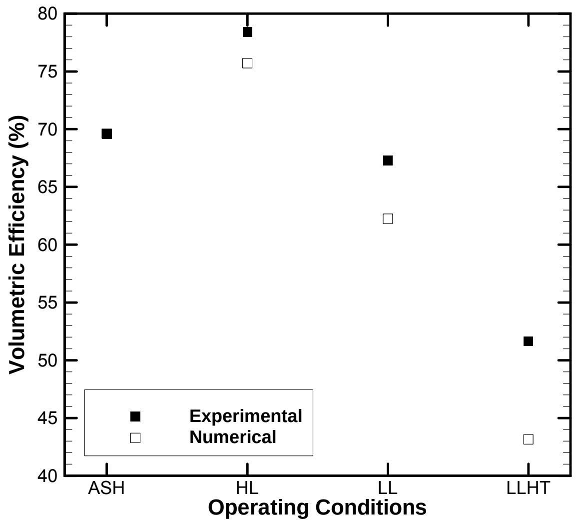
Solution flowchart:

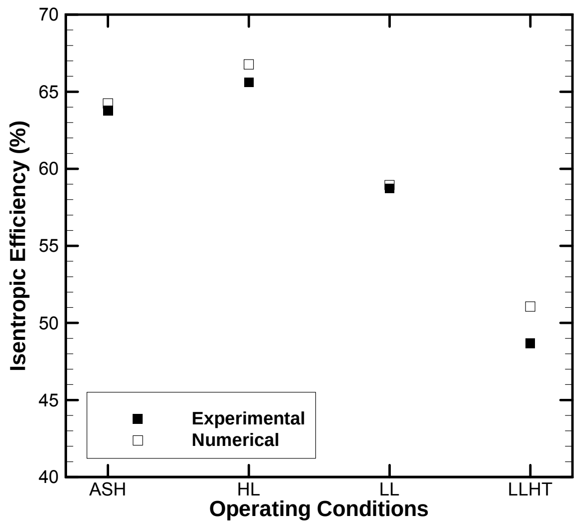


RESULTS

Simulations were run under four operating conditions:

O.C.	T_E (°C)	T_C (°C)	T_{SH} (°C)	T_{AIR} (°C)
ASH	-23.3	54.4	32.0	32.0
HL	-10.0	60.0	32.0	32.0
LL	-35.0	45.0	32.0	32.0
LLHT	-35.0	70.0	40.0	43.0

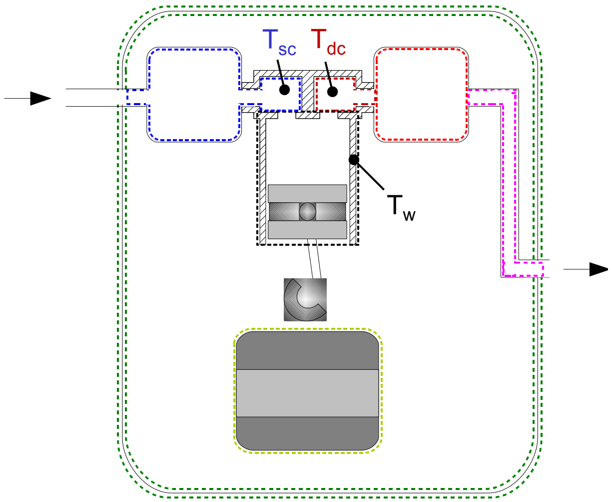


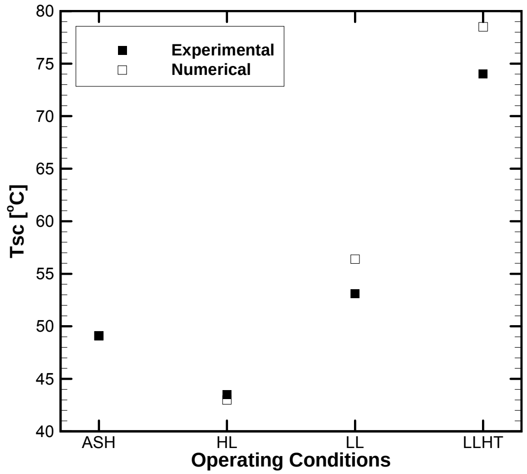


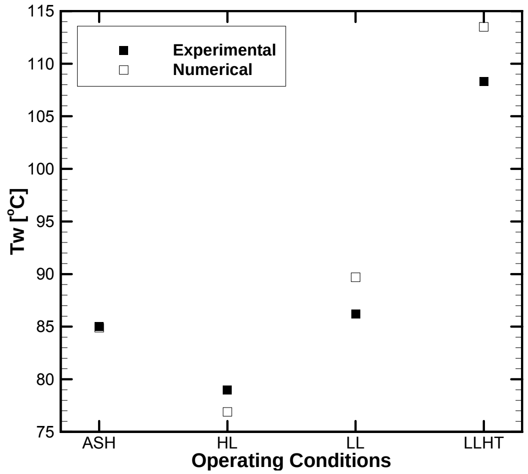
- Numerical results agree with experimental data trends;
- Num-Exp. deviations ≤ **5%** at **HL** and **LL**;
- Num-Exp. deviations up to **9%** at **LLHT.**

RESULTS

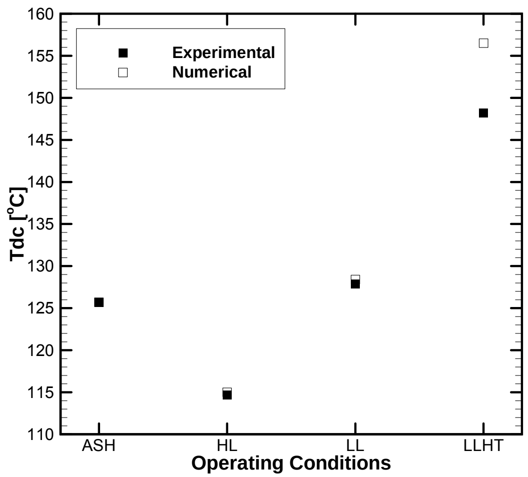
Temperature results:





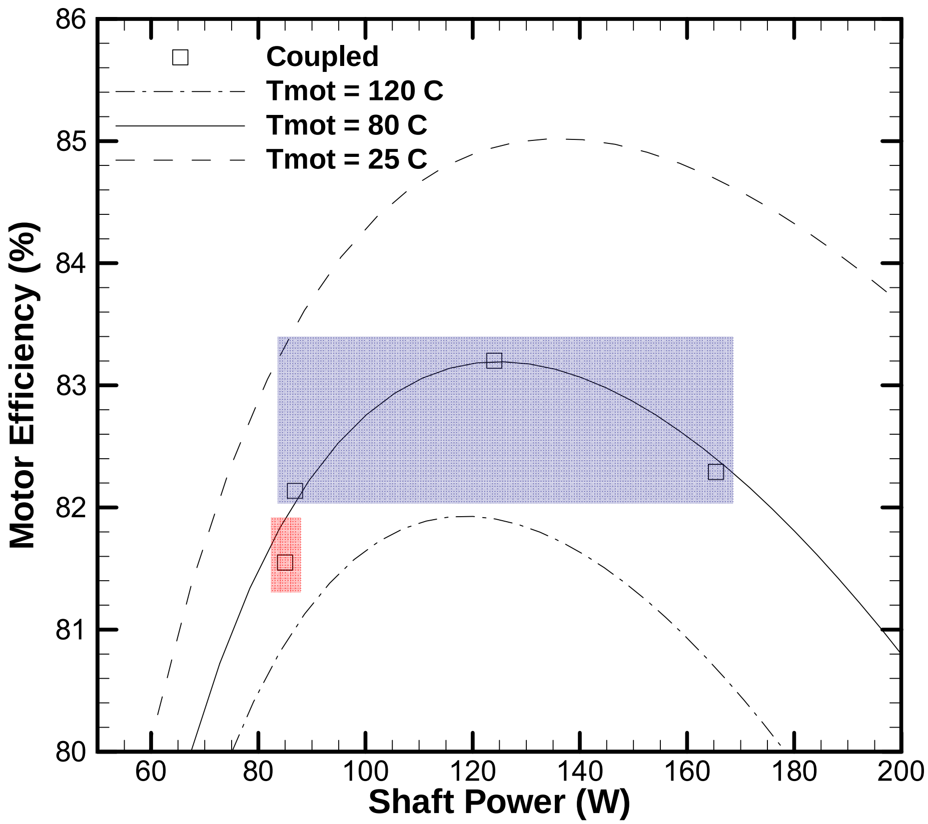


- T_{sc}, T_w and T_{dc} trends are well predicted;
- Most of Num – Exp. deviations ≤ **5ºC.**



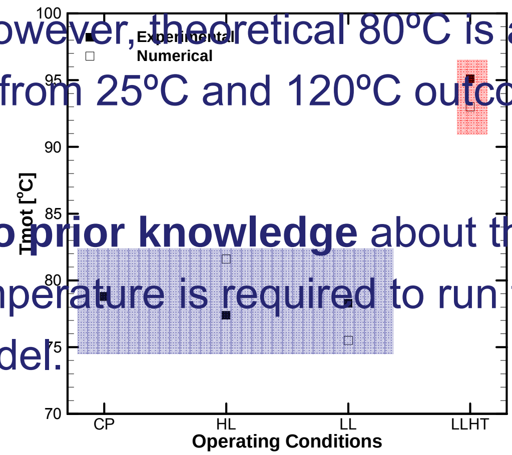
RESULTS

Motor efficiency:



• Motor efficiency predicted by the coupled model is close to a theoretical 80ºC constant temperature prediction;

• However, theoretical 80ºC is at least 1% far from 25ºC and 120ºC outcomes;



• **No prior knowledge** about the motor temperature is required to run the coupled model.

CONCLUSIONS

• It was presented a lumped-parameter model for hermetic reciprocating compressors based on the coupling of thermodynamic, thermal and electrical models;

• Reasonable agreement is observed between predictions and experimental data for volumetric and isentropic efficiencies as well as compressor temperatures;

• The model proposed herein is capable of accounting for the effect of motor losses on the compressor thermal profile and vice-versa;

• Finally, the coupled model does not require experimental or theoretical estimates concerning motor efficiency, torque and speed to be used as input data.

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Thank you!

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