S I R A C H

University of South Wales

Brunel University London

Performance Investigation and Optimisation of Finned-tube CO_2 Gas Coolers and Evaporators

Professor Yunting Ge
Yunting.ge@southwales.ac.uk
University of South Wales

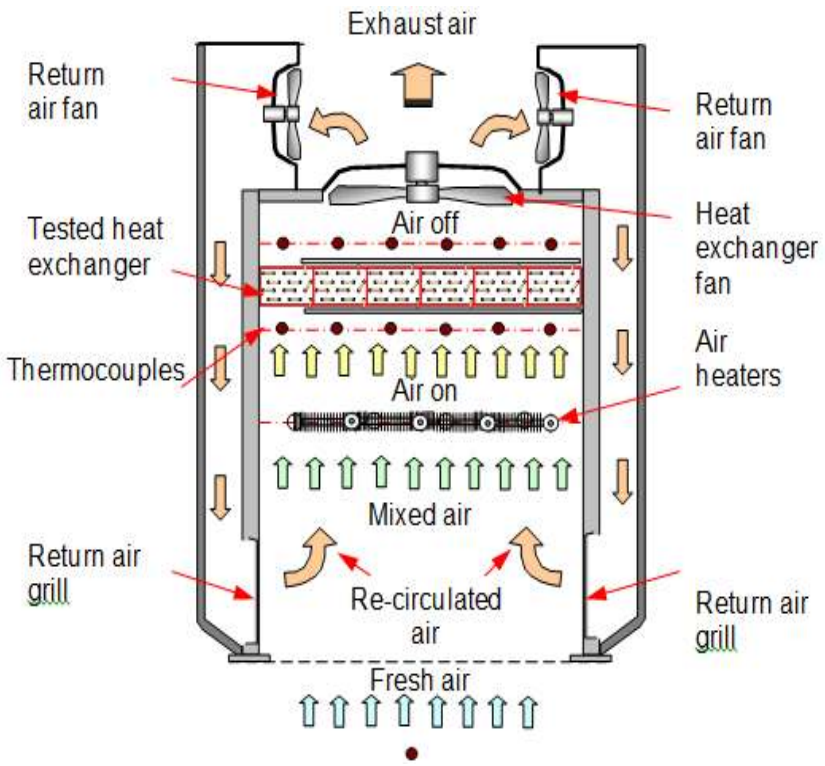
sirach
www.sirach.org.uk

S I R A C H

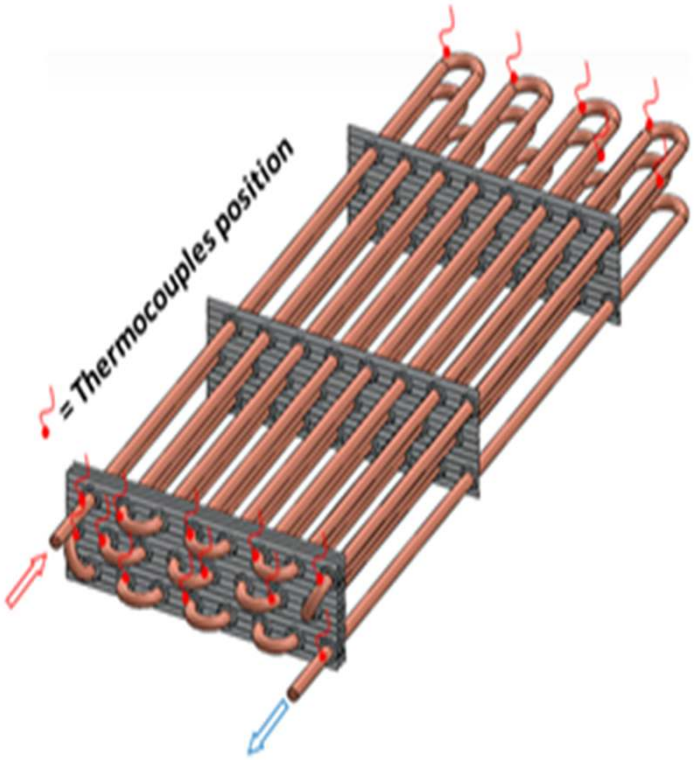
Background

- As a natural refrigerant (working fluid), CO_2 has been widely used in refrigeration and heat pump systems.
- Due to simplified structural design and application requirement, finned-tube CO_2 gas coolers/condensers and CO_2 evaporators are conventionally used in the CO_2 refrigeration/heat pump systems.
- It is understood that high efficient CO_2 gas cooler/condenser and evaporator and corresponding controls can significantly improve the overall system performance.
- Subsequently, CO_2 heat exchangers have been optimised by means of experimental and theoretical analysis.

Experimental Facilities:CO_2 Gas Cooler/Condenser

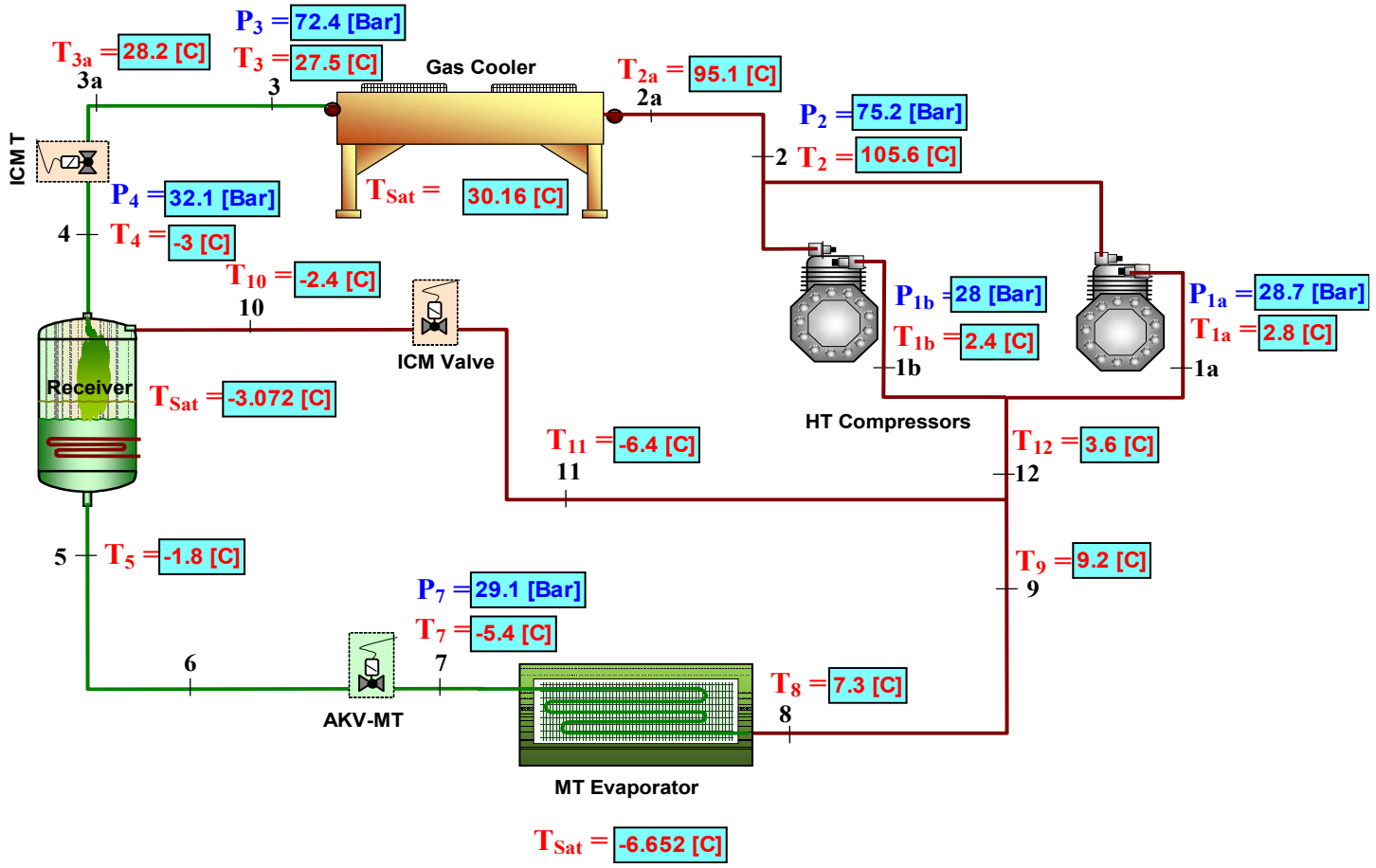


Test rig of CO_2 gas cooler & condenser

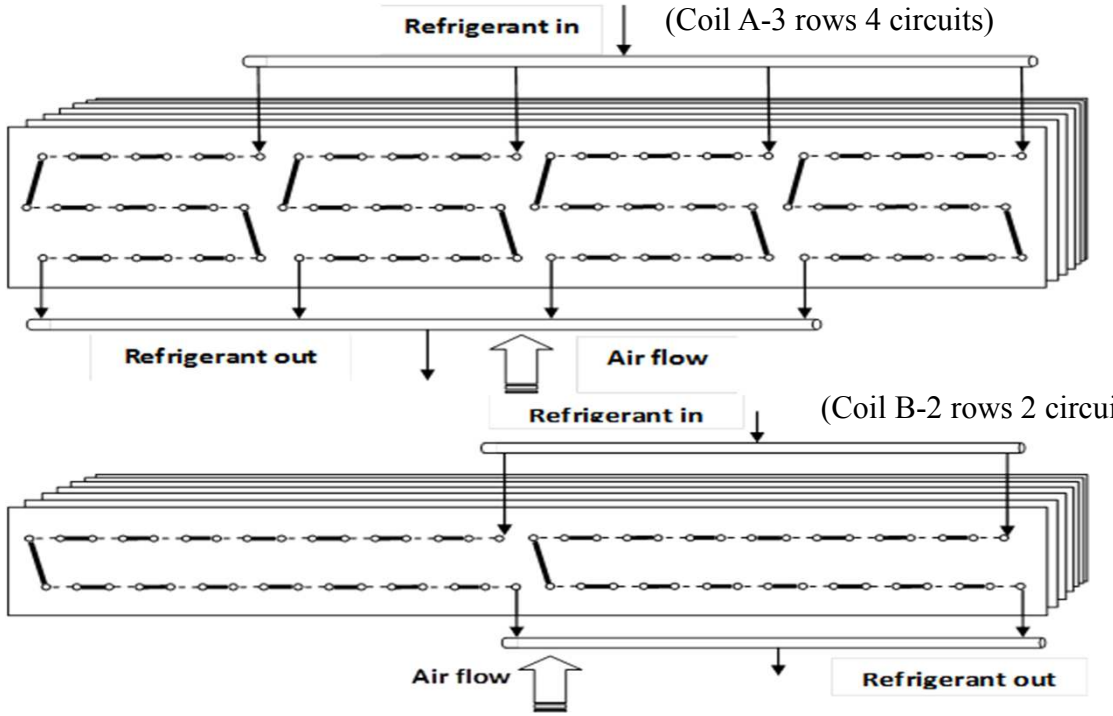


Pipe arrangement and thermocouple

Experimental Facilities: CO_2 Gas Cooler/Condenser and its Integrated Refrigeration System



Two tested finned-tube CO_2 gas coolers/condensers



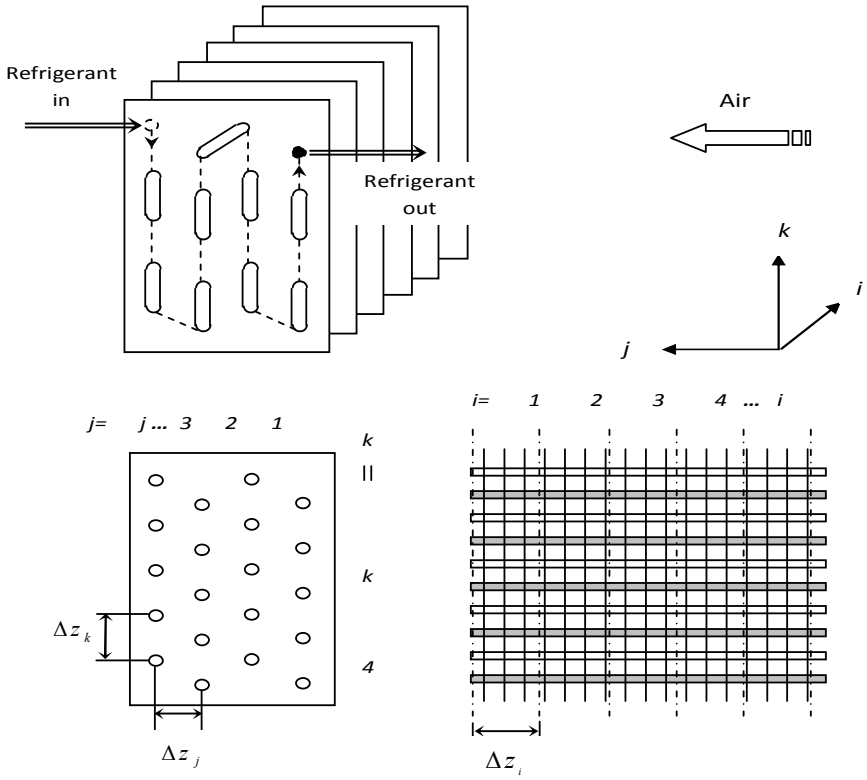
Test conditions of CO_2 heat exchangers for both gas cooler and condenser modes

Mode	HX Type	No. of Tests	Test ranges				
			T_{ain}	$\dot{V}_a$	T_{rin}	P_{rin}	$\dot{m}_r$
			°C	l/s	°C	bar	kg/s
Gas cooler	3 Rows	15	28~35	2000~2800	90~120	75~90	0.036~0.042
	2 Rows	19	28~35	2000~2800	90~120	75~90	0.036~0.042
Condenser	3 Rows	16	19~29	2000~2800	71~90	60~73	0.031~0.040
	2 Rows	17	19~29	2000~2800	71~90	60~73	0.031~0.040

S I R A C H

Mathematical model of CO_2 gas cooler/condenser

Method 1: Distributed Model



Method I

Detailed Method

3D coordinates

Localised correlations: Heat and mass transfer

Local parameters: temperature – pressure – heat transfer rate

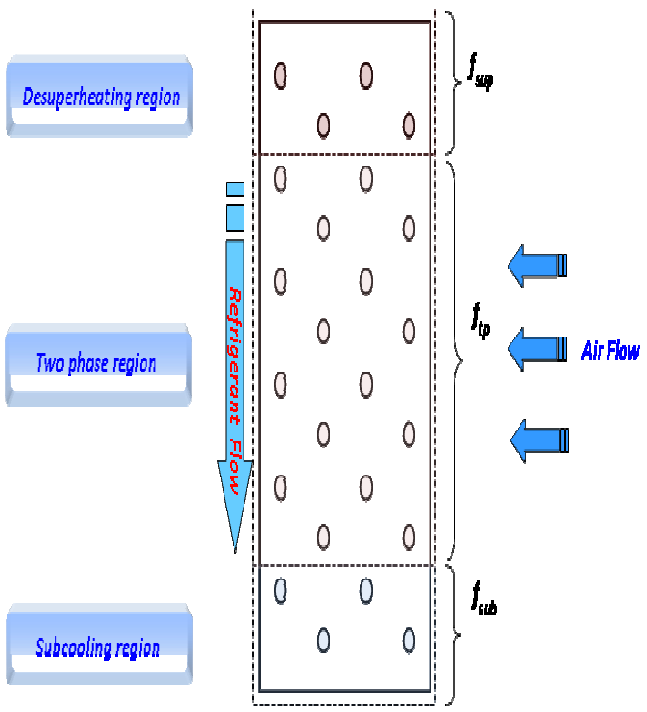
Prediction: Hot and Cold fluid flowing along the pipes

Requires long computation time

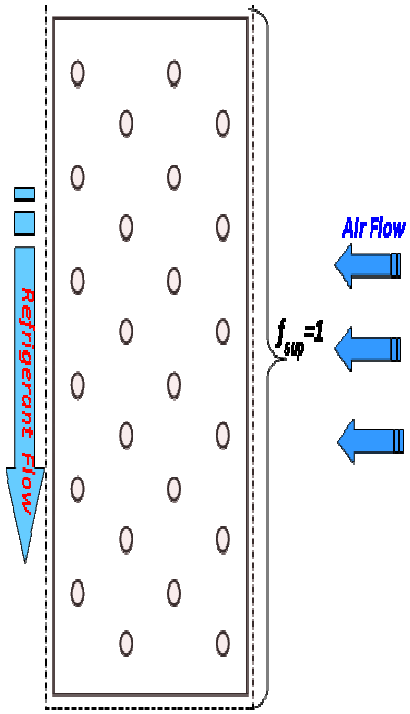
SIRACH

Method 2: Lumped Method/Simple Model

✓ **Condenser Model**



✓ **Gas Cooler Model**



Method 2

Simple model

Limited number of segments

Conservation equations: mass – momentum - energy

More Practical to model a system

Short computation time

Used for this paper

Method 2: Model Description

Conservation equations are applied to each section

The heat transfer from the refrigerant side :

$$\dot{Q} = \dot{m}_r(h_{in} - h_{out})$$

Heat balance between refrigerant and air flows :

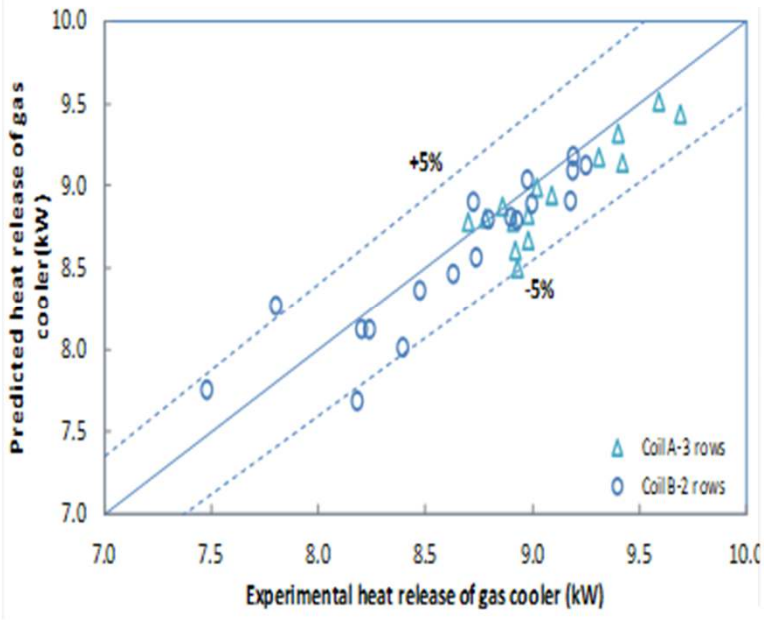
$$\dot{Q} = \dot{V}_a \rho_a C_{pa}(T_{ain} - T_{aout})/1000.0$$
$$= \varepsilon(G_c)_{min}(T_{rin} - T_{ain})$$

$$\varepsilon = \begin{cases} \dfrac{1-\exp\left(-(1-\exp(-Ntu))(G_c)_{min}/(G_c)_{max}\right)}{(G_c)_{min}/(G_c)_{max}} & \text{for refrigerant in single-phase} \\ 1-\exp(-Ntu) & \text{for refrigerant in two-phase} \end{cases}$$

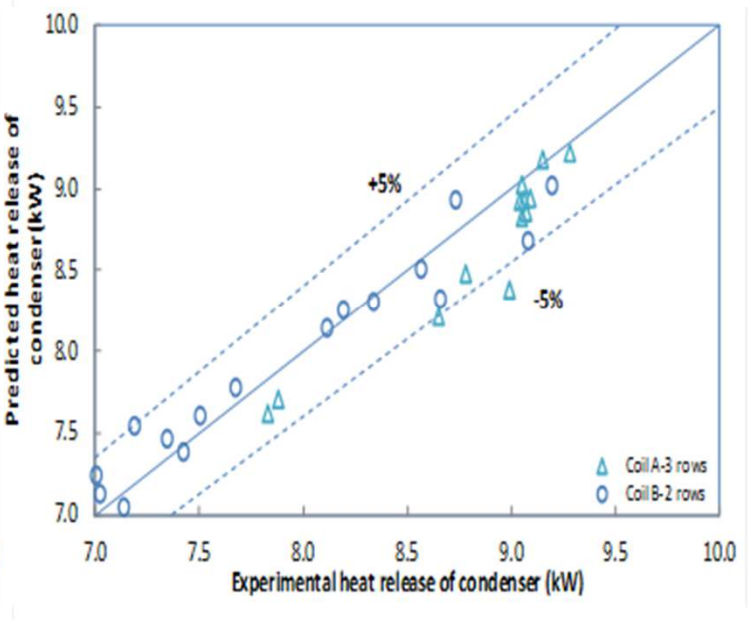
$$Ntu = \frac{(UA)_{tot}}{(G_c)_{min}} \qquad (UA)_{tot} = \frac{1}{\frac{1}{(UA)_o}+\frac{1}{(UA)_i}} = \frac{1}{\frac{1}{\eta_f \alpha_o A_o}+\frac{1}{U_i A_i}}$$

S I R A C H

Comparison of simulation and experimental results



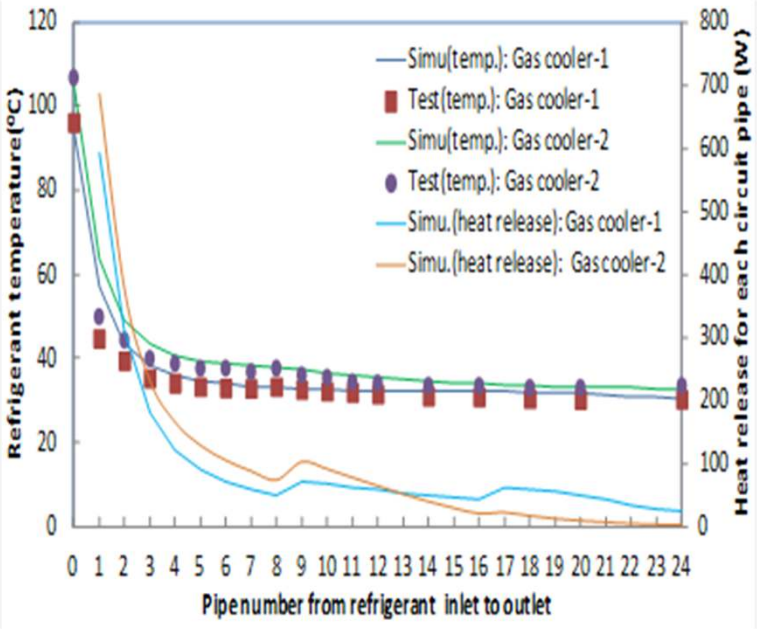
Comparison of simulation and test results for heat release of gas cooler



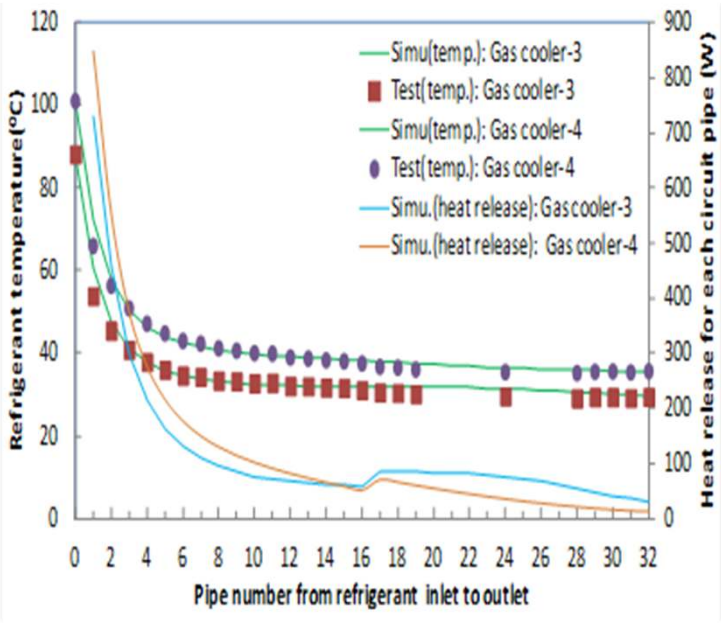
Comparison of simulation and test results for heat release of condenser

sirach
www.sirach.org.uk

Model Application-detailed model



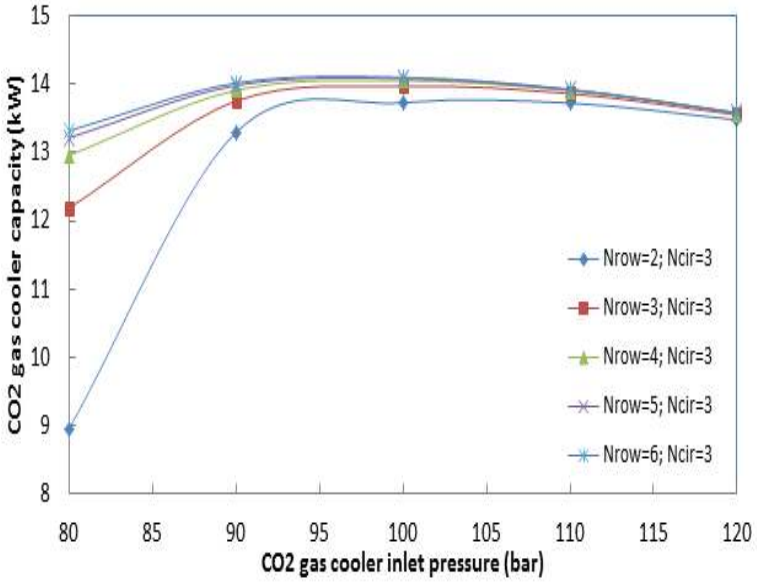
Profiles of temperature and heat transfer rate along the pipes of each circuit for the 3-row gas cooler



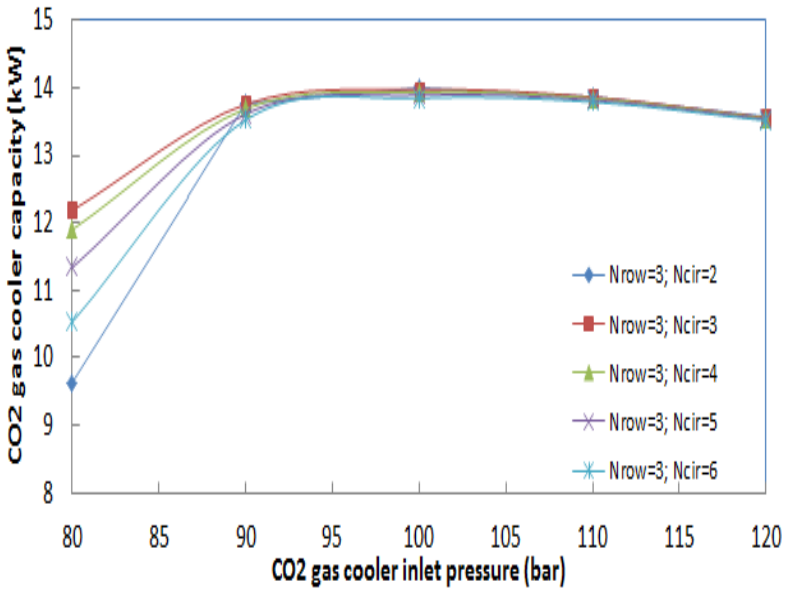
Profiles of temperature and heat transfer rate along the pipes of each circuit for the 2-row gas cooler

Model Application-simple model

Effect of numbers of pipe rows and circuits on HX capacity



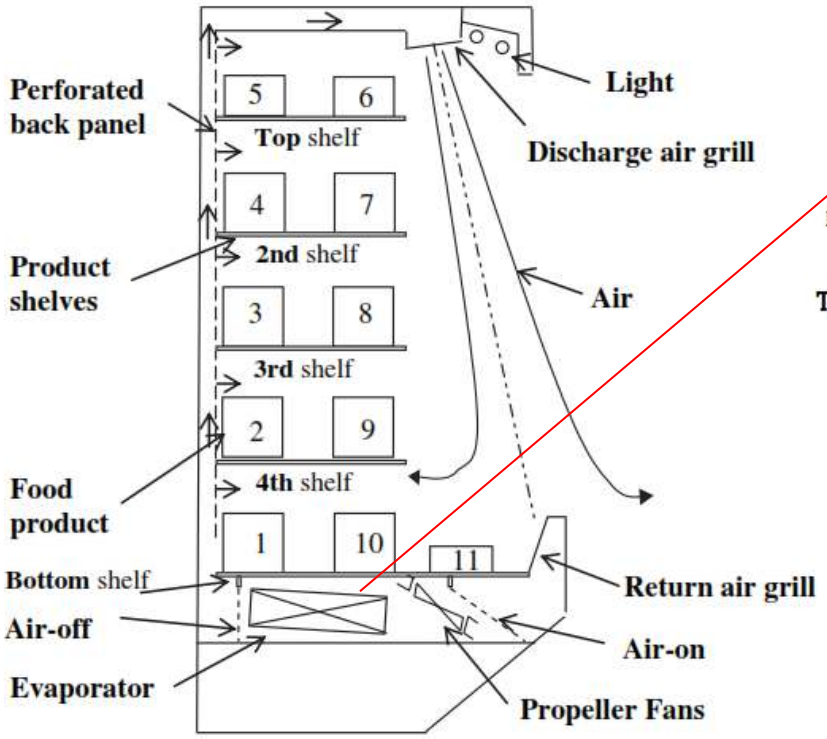
Variation of CO_2 gas cooler capacity with supercritical gas cooler pressure and numbers of pipe rows



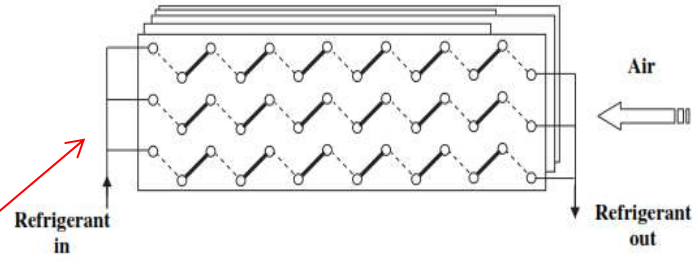
Variation of CO_2 gas cooler capacity with supercritical gas cooler pressure and numbers of pipe circuits

The impact of geometric structure and flow arrangement on the performance of CO2 evaporators in multi-deck medium temperature display cabinets

Descriptions of the display cabinet



Prototype Carter display cabinet

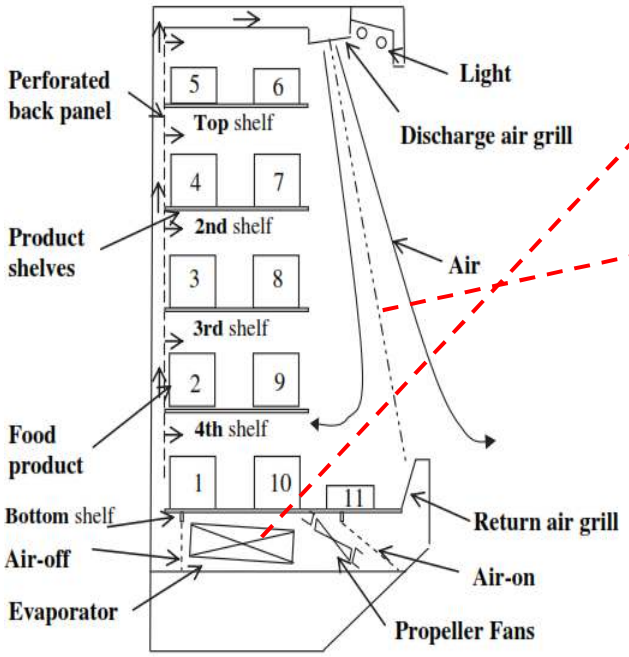


The R404A evaporator in the prototype display cabinet.

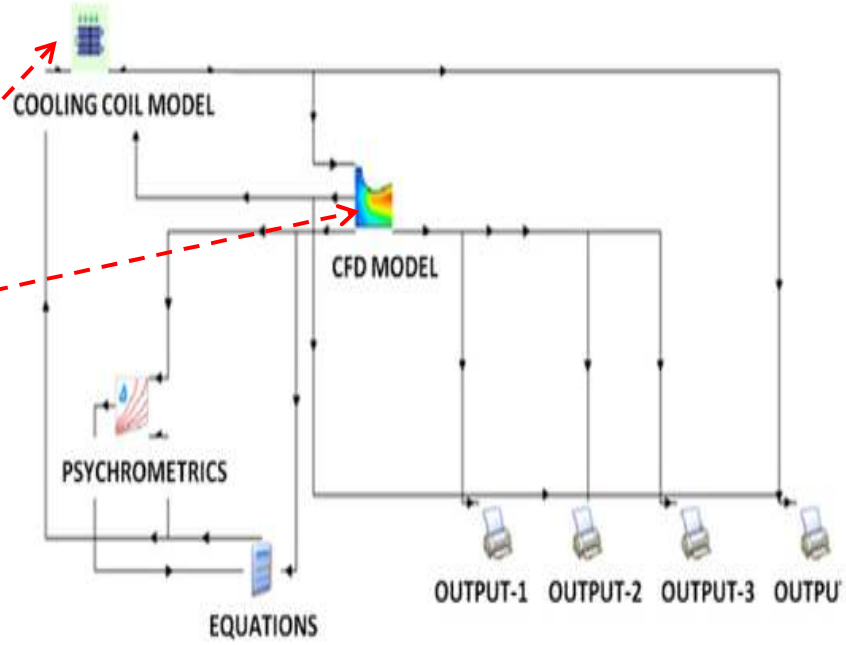
- Length of 2.06 m along the pipes;
- Height of 0.156 m in the transverse direction;
- Depth of 0.42 m in the longitudinal direction;
- The pipe outer and inner diameters of 15.875 mm and 14.875 mm respectively;
- The pipe spacing of 30 mm in the longitudinal direction and 52 mm in the transverse direction;
- The fin spacing of 14.7 mm for the first two rows from the air-on and 7.35 mm afterwards;
- The fin thickness of 0.2 mm with a flat pattern.

SIRACH

Model description of display cabinet and validation



Prototype Carter display cabinet

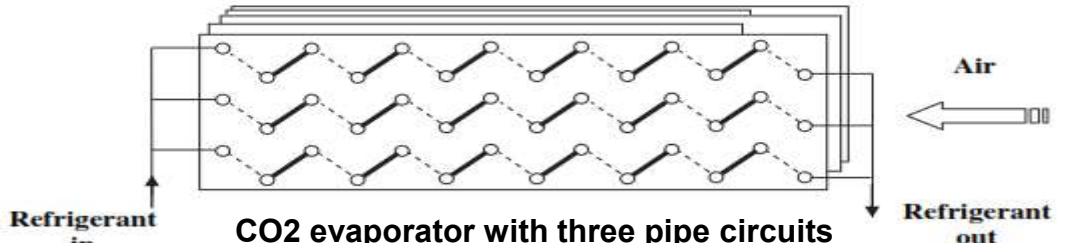


Integration of the CFD and cooling coil models under the simulation environment of TRNSYS.

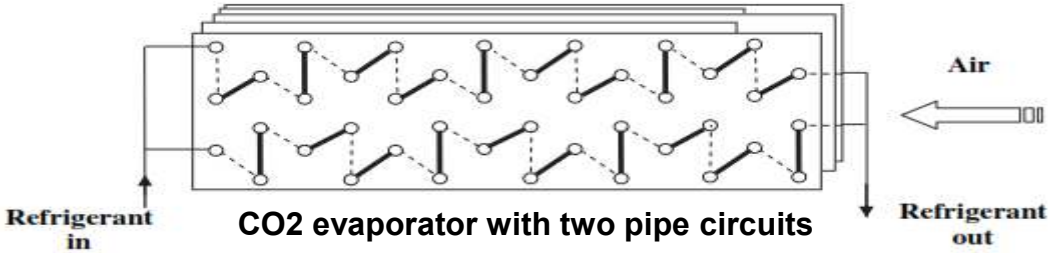
Design options for CO2 cabinet evaporators

Table 1 – Design options for CO_2 cabinet evaporators.

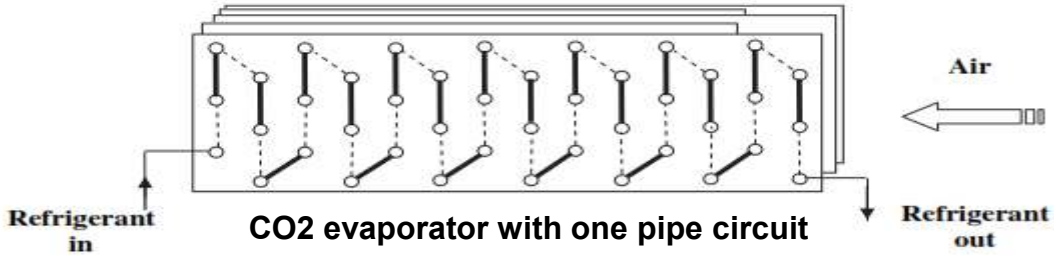
Parameters	Design options								
	1	2	3	4	5	6	7	8	9
D_0 (mm)	15.875	12.7	9.525	15.875	12.7	9.525	15.875	12.7	9.525
D_i (mm)	13.875	10.7	7.925	13.875	10.7	7.925	13.875	10.7	7.925
Circuit number	3	3	3	2	2	2	1	1	1



CO2 evaporator with three pipe circuits



CO2 evaporator with two pipe circuits



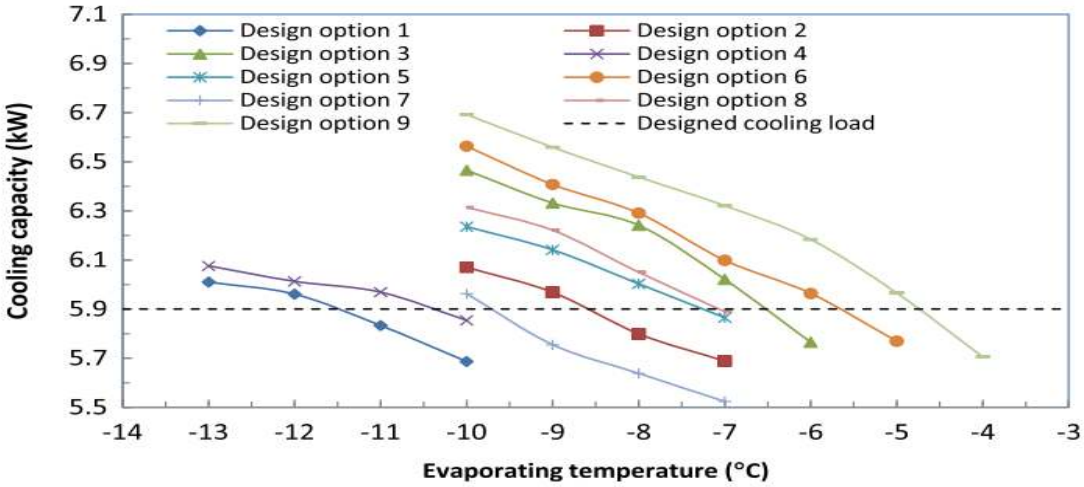
CO2 evaporator with one pipe circuit

SIRACH

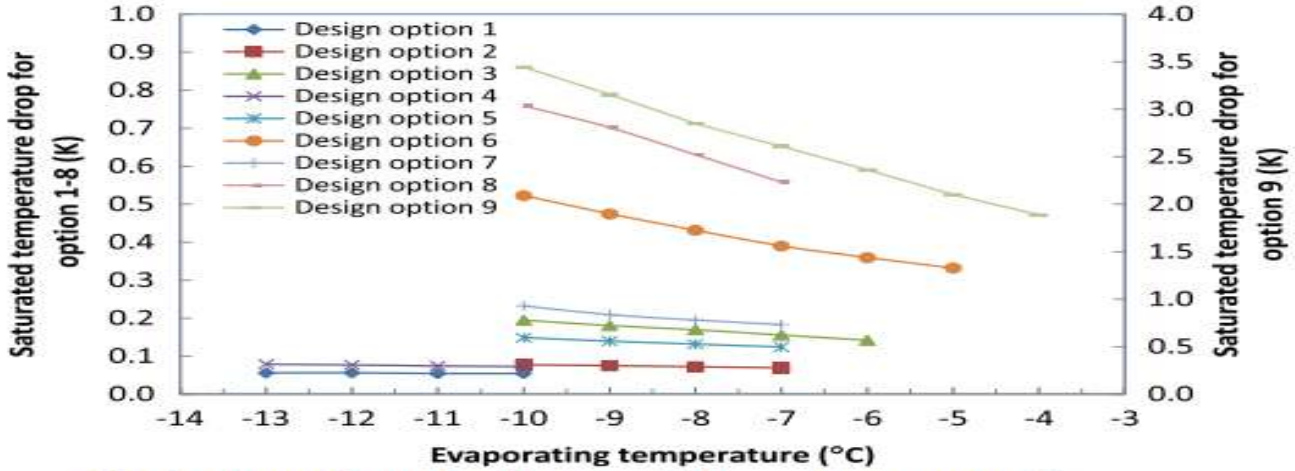
sirach
www.sirach.org.uk

S I R A C H

Performance evaluation for different designs of CO_2 evaporators



Variation of cooling capacity with evaporating temperature for different design options.



Variation of equivalent refrigerant saturated temperature drop with evaporating temperature for different design options.

Conclusions

- Finned-tube CO2 gas cooler/condenser and evaporator play important roles in CO2 refrigeration/heat pump system which can be optimised in structural designs and circuit arrangements by means of modelling and experiment
- The CO2 gas cooler/condenser and evaporator models can be developed by both distributed and lump methods and need to be validated with experiment.
- For the CO2 gas coolers , the numbers of pipe row and circuit can be optimised to maximize the HX capacity.
- For the CO2 evaporators, the pipe circuits and sizes affect significantly on the HX capacity and system performance but also HX pressure drop.

S I R A C H

Thank You!

sirach
www.sirach.org.uk