

OPTIMIZING BLIND CURTAIN SIZE IN TRUCKS USING THE KULI MODEL

PURPOSE

Developing a Kuli model to estimate the ice formation and optimize the blind curtain size in truck intercooler

ICE TRUCK COOLING SYSTEM

6 Cylinder ICE- Cooling system

ICE Cooling system:

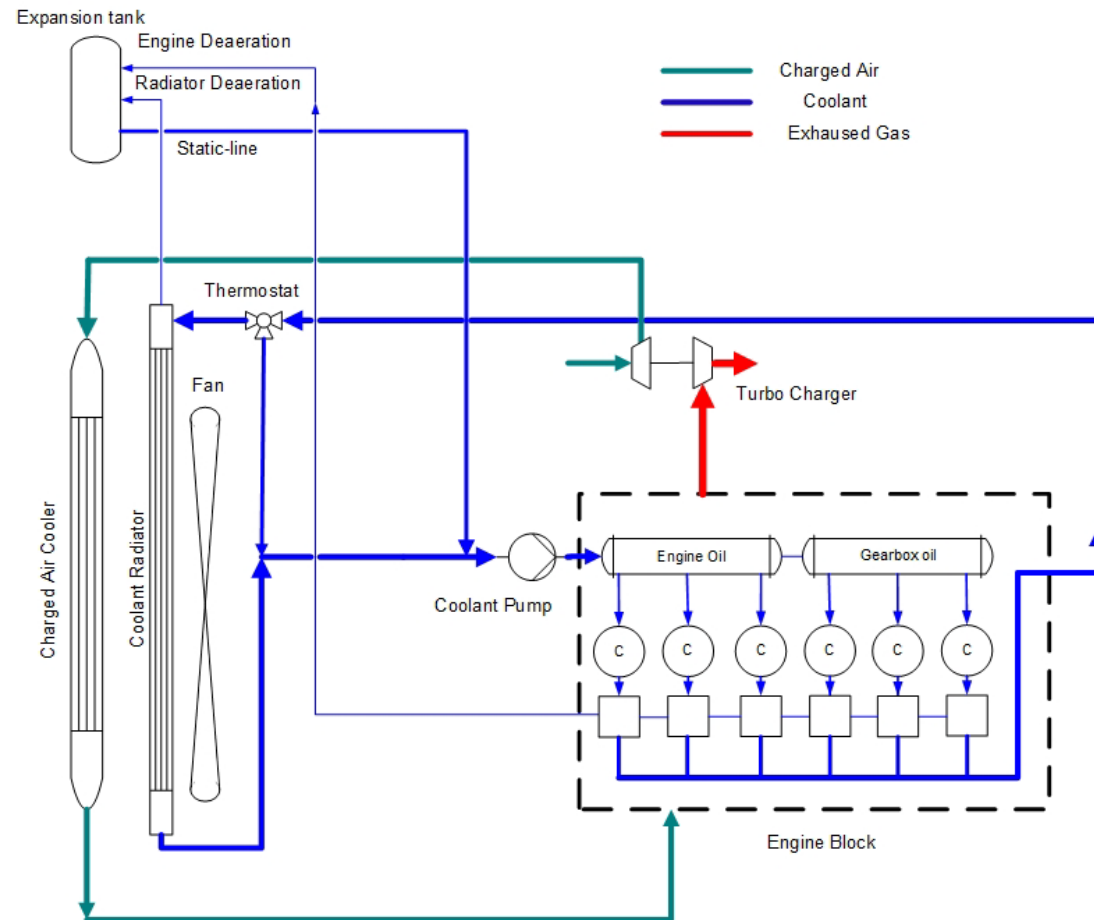
Engine cooling system

Charged air cooling system

Gearbox cooling system

Auxiliary brake cooling system

etc.



Example

WARM CLIMATE

Ambient:

Temperature : +25°C

Pressure: 1,013 bar

Air flow: 12 kg/min

After compressor/ before cooler:

Temperature: +110°C

Pressure: 1.8 bar

Air flow: 12 kg/min

After cooler: (verified by test)

Temperature: +27°C

Pressure: 1.78 bar

Air flow: 12 kg/min

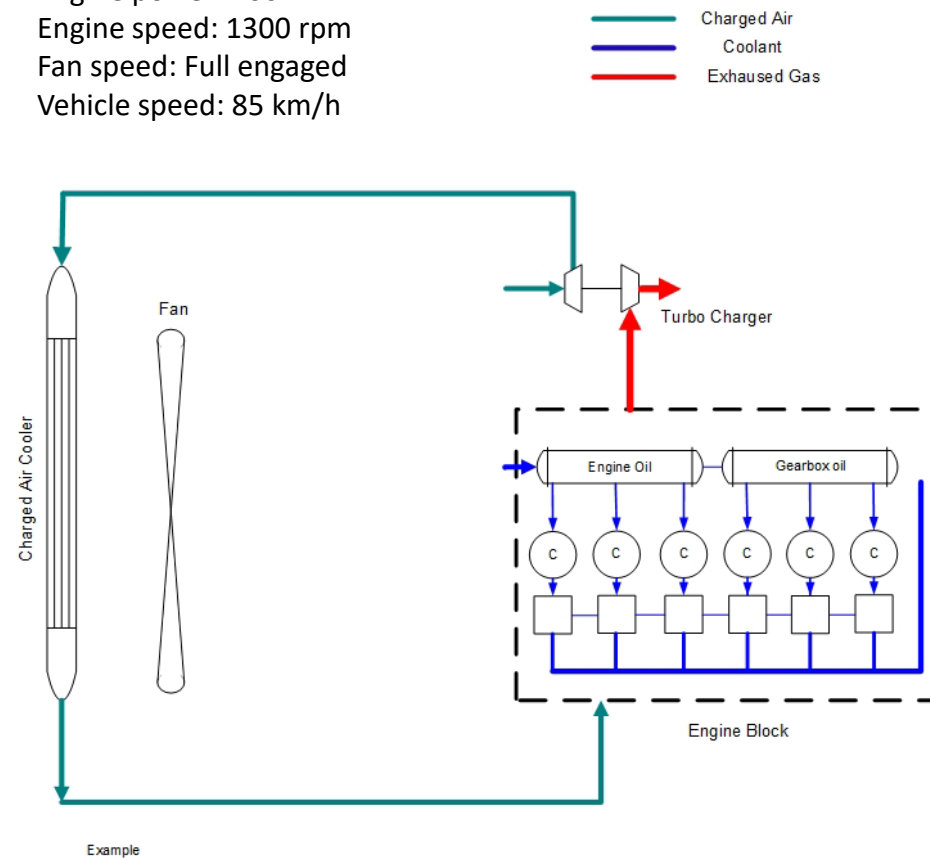
Example:

Engine power: 200 kW

Engine speed: 1300 rpm

Fan speed: Full engaged

Vehicle speed: 85 km/h



COLD CLIMATE, HUMIDITY, PSYCHROMETRIC CHARTS & EMPIRICAL METHODS

Ambient:

Temperature : -20°C

Pressure: 1,013 bar

Air flow: 12 kg/min

Humidity: $\phi=100\%$ ($\omega=0.63$ g/kg)

After compressor/ before cooler:

Temperature: +57°C

Pressure: 1.9 bar

Air flow: 12 kg/min

Humidity: $\phi=100\%$ ($\omega=61.8$ g/kg)

After cooler:

Temperature: -19°C

Pressure: 1.88 bar

Air flow: 12 kg/min

Humidity: $\phi=100\%$ ($\omega=0.37$ g/kg)

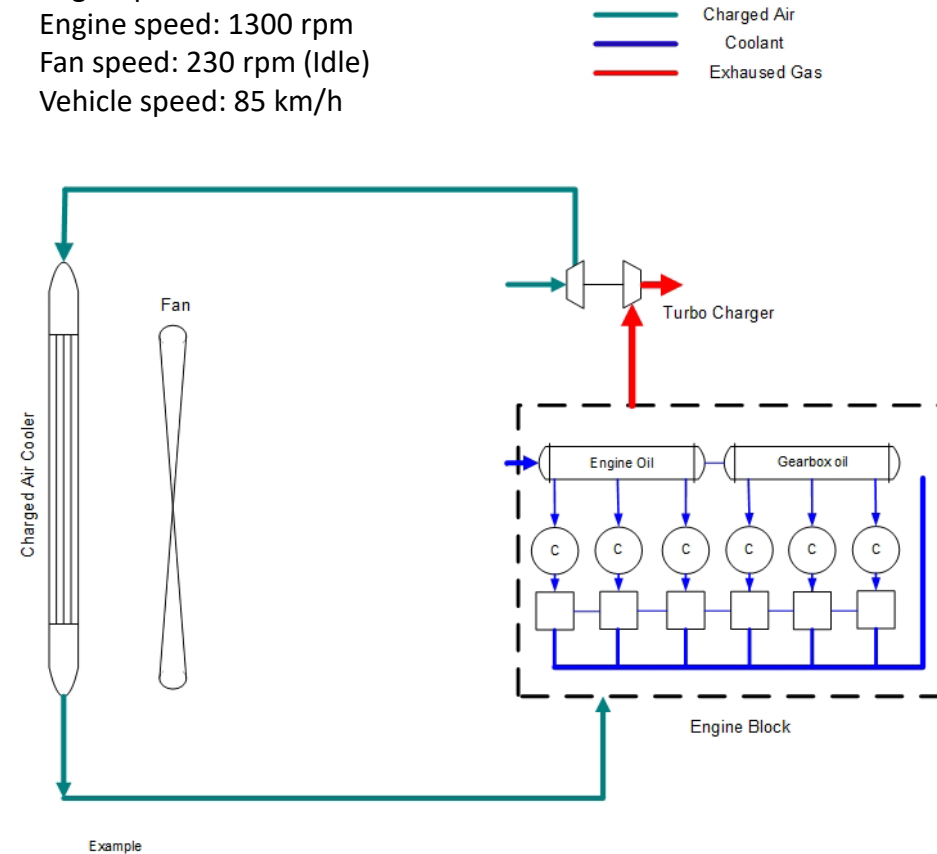
Example:

Engine power: 200 kW

Engine speed: 1300 rpm

Fan speed: 230 rpm (Idle)

Vehicle speed: 85 km/h



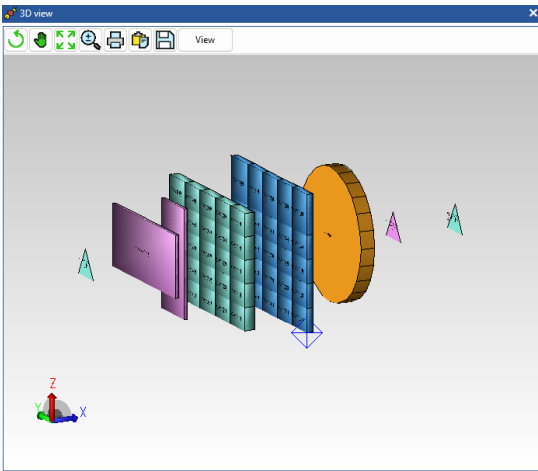
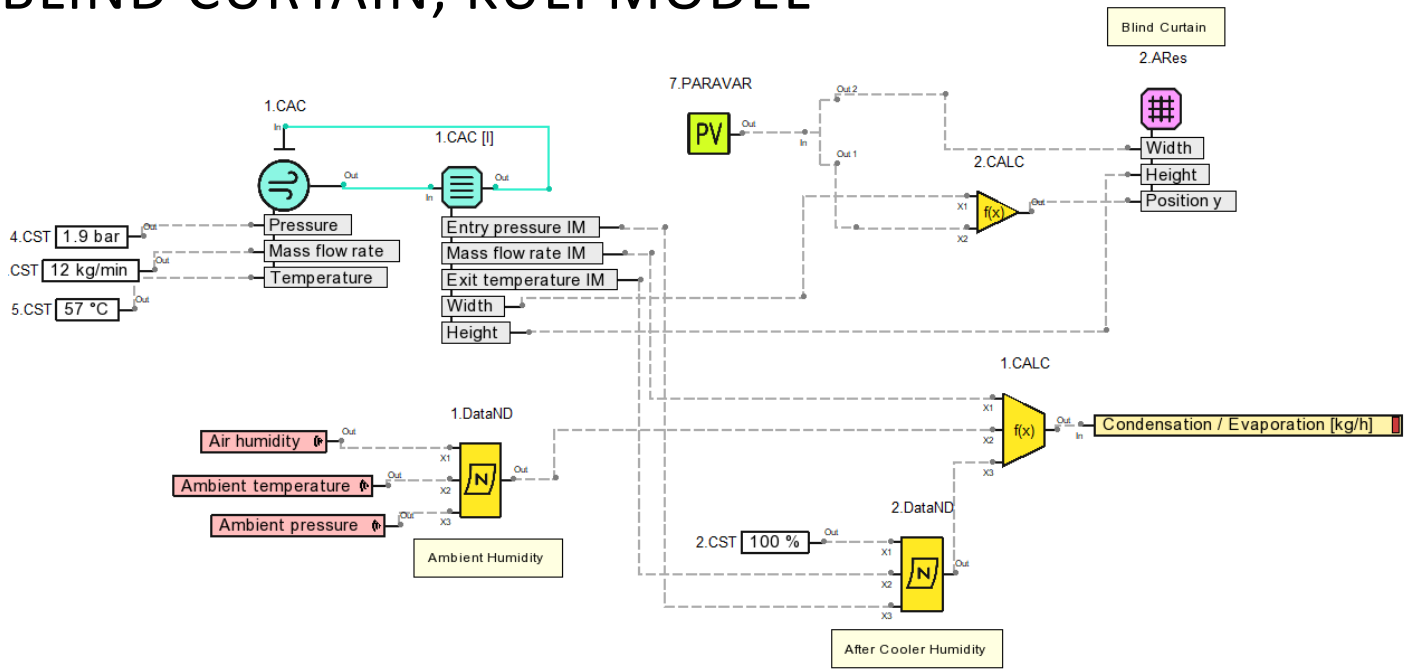
$$\text{Ice formation rate} = (0.63 - 0.37) \text{ [g/kg]} \times 12 \text{ [kg/min]} = 3.1 \text{ gr/min} = 188 \text{ gr/hr}$$

ICE FORMATION IN THE CHARGE AIR COOLER

- Reduction of charged air flow
- Increased intake pressure drop
- Engine power loss
- Ice chunk into engine
- Sensors malfunction
- VOR
- etc.



BLIND CURTAIN, KULI MODEL



General data

No. of Dimension values: 3

No. of Values: 1

Use standard char. line, map or multimap

Method: IMSL

Class Limit: 0

Classify X: 0

Dimension 1 [%]...	Dimension 2 [°C]...	Dimension 3 [bar]...	Value 1 [kg/kg]...
100	-20	5	0.000126922
100	-19	0.8	0.000873873
100	-19	0.9	0.000776655
100	-19	1	0.000698902
100	-19	1.1	0.000635301
100	-19	1.2	0.00058231
100	-19	1.3	0.000537478
100	-19	1.4	0.000499056
100	-19	1.5	0.00046576
100	-19	1.6	0.00043663
100	-19	1.7	0.000410929
100	-19	1.8	0.000388085
100	-19	1.9	0.000367648
100	-19	2	0.000349255
100	-19	2.1	0.000332615
100	-19	2.2	0.000317488
100	-19	2.3	0.000303678
100	-19	2.4	0.000291019
100	-19	2.5	0.000279373
100	-19	2.6	0.000268623
100	-19	2.7	0.00025867

ESTIMATION OF BLIND CURTAIN WIDTH

Ambient:

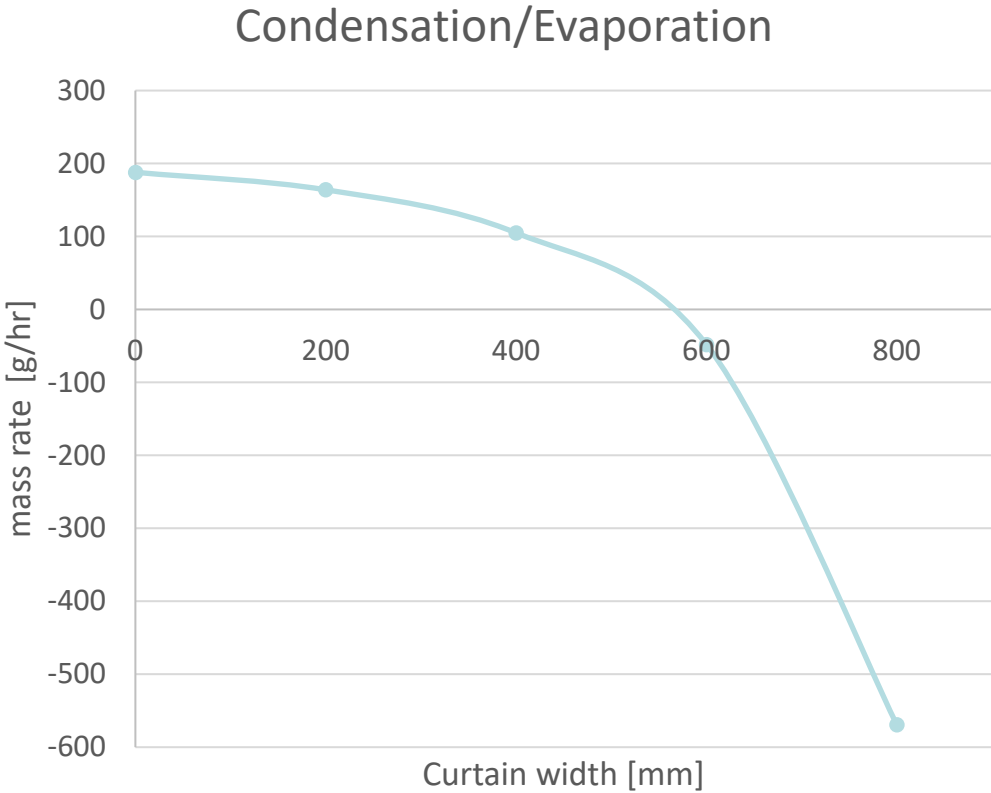
Temperature : -20°C , Pressure: 1,013 bar, Air flow: 12 kg/min
Humidity: $\phi=100\%$ ($\omega=0.63$ g/kg)

After compressor/ before cooler:

Temperature: +57°C, Pressure: 1.9 bar, Air flow: 12 kg/min
Humidity: $\phi=100\%$ ($\omega=61.8$ g/kg)

After cooler: Pressure: 1.88 bar, Air flow: 12 kg/min

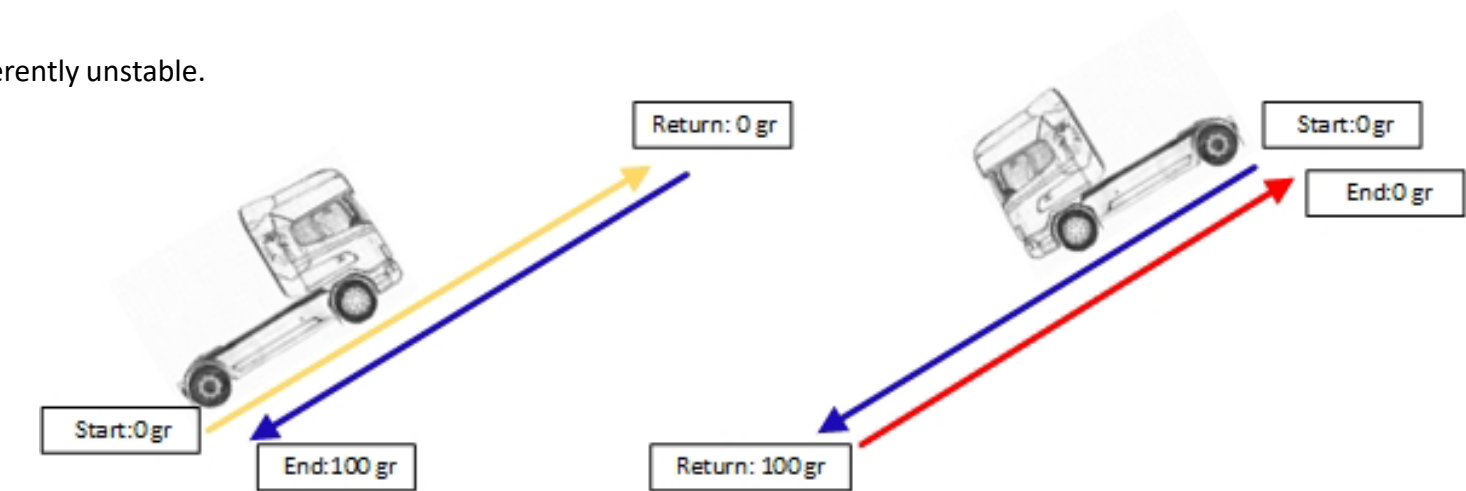
- WO Curtain: T= -19 °C , $\phi=100\%$ ($\omega=0.37$ g/kg) $\Rightarrow$ ~ 188 gr/hr ☹
- 400 mm Curtain: T= -16 °C , $\phi=100\%$ ($\omega=0.48$ g/kg) $\Rightarrow$ ~ 105 gr/hr ☹
- 800 mm Curtain: T= - 4 °C , $\phi=100\%$ ($\omega=1.42$ g/kg) $\Rightarrow$ ~ -568 gr/hr ☺



Component	Simulation parameters 1 ▶				Speed-controlled fan 1	Area resistance 2	Charge air cooler 1 ▶						N-dimensional map 1	N-dimensional map 2	COM object 1
Value	Ambient temperature	Ambient pressure	Relative humidity	Driving speed	Input speed	Width	Mass flow r...	Entry press...	Entry temp...	Exit temper...	Exit pressure IM	Thermal output IM	Current Value	Current Value	Current Value
Unit	°C	bar	%	km/h	1/min	mm	kg/min	bar	°C	°C	bar	kW	kg/kg	kg/kg	kg/h
1	-20	1,013	100	85	230	400	12	1,9	57	-16,1384	1,8825	14,7618	6,2761E-04	4,814E-04	0,1053

DRIVING CYCLES

- A true transient model requires extensive input data and tends to be inherently unstable.



Time distribution for an imaginary duty cycle:

Load (%)	Engine Speed 1000 rpm	Engine Speed 1500 rpm	Engine Speed 1700 rpm
25%	10	38	10
50%	5	15	5
75%	2	3	3
100%	2	4	3

- Instead, multiple steady-state points are used to approximate real driving conditions.

AMBIENT TEMPERATURE, ACCEPTANCE CRITERIUM, RECOMMENDATION

- Inlet humidity depends on temperature ($\phi = 100\%$, 1 bar). For example, at -30°C the humidity is significantly lower than at -5°C (0.234 g/kg vs. 2.486 g/kg).
- Some level of ice formation is acceptable, as long as it remains below a threshold ($M < X \text{ g/h}$).
- Estimations are also made for temperatures above freezing, e.g., $+10^{\circ}\text{C}$
- Selecting the correct width is highly dependent on factors such as the duty cycle, ambient temperature and humidity, and other operating conditions.

Ice formation [g/hr] for an imaginary duty cycle:

Curtain [mm]	-30°C	-20°C	-10°C	0°C
0	60	180	400	1100
200	40	100	300	850
400	-30	-50	20	300
600	-250	-400	-750	-1000
800	-950	-1900	-3500	-5500

Recommendation:

Engine	Cooler	WO Curtain	200 mm	400 mm	600 mm	800 mm
Low Power	Small	NOK	OK	Best	OK	NOK
	Large	NOK	NOK	OK	Best	OK
High Power	Small	NOK	Best	OK	NOK	NOK
	Large	NOK	OK	Best	OK	NOK

Summary:

- *Kuli can be used to estimate ice formation in a truck intercooler, which may lead to serious operational issues.*
- *Kuli also helps determine the optimal width of the blind curtain to reduce ice accumulation.*
- *Several thermodynamic principles are integrated into Kuli to improve prediction accuracy.*
- *While direct verification of ice mass is challenging (ongoing measurement campaign), temperature measurements with the curtain in place have been validated through testing.*

