Development and Validation of a Minichannel Evaporator 2D Model under Dehumidification

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INTRODUCTION

In this study, a two-dimensional numerical model for a minichannel evaporator is implemented. This model takes into account the variation of wall (fin and tube) temperature and moist air properties (temperature and humidity ratio) in both longitudinal and transverse directions. After the validation with a well defined analytical case, the model is used to simulate a real case study. The results under different scenarios for the tube and fin (totally wet, totally dry, or partially wet) are compared with the traditional ε-NTU approach.

EVAPORATOR DISCRETIZATION

Figure (1a), presents a piece of the studied minichannel evaporator. It is discretized along the X-direction (refrigerant flow) in a number of segments "a". Each segment (Figure 1b) consists of: two streams of refrigerant (top and bottom flows) that are split into "b" channels in the Z-direction (air flow); two flat tubes (top and bottom) that are discretized into "c" cells in the Z-direction; and both air flow and fins, which are discretized in two dimensions: "d" cells in the Y-direction and "e" cells in the Z-direction. This is summarized in the text as; grid: {a,b,c,d,e}.

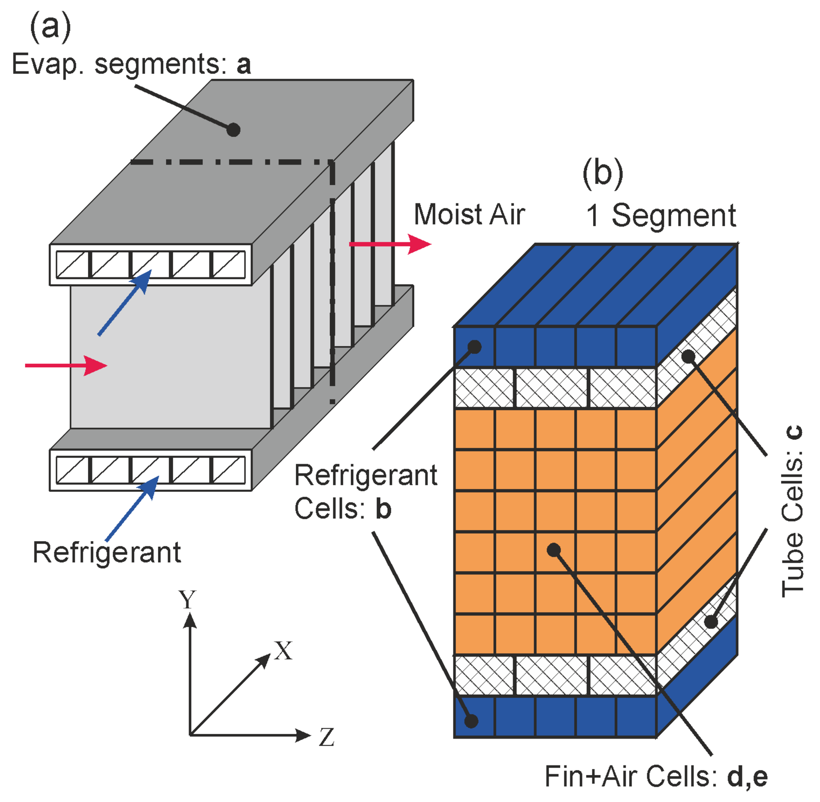

Figure 1: Evaporator discretization schema

CASE STUDY

Table 1: Geometry of the minichannel evaporator

Tube Length	(cm)	8.6	Fin pitch	(mm)	1.59	Channel Diameter	(mm)	1
Tube Depth	(mm)	1.6	Fin thickness	(mm)	0.152	Channels Number	(-)	10
Tube Thickness	(mm)	0.5	Fin height	(mm)	8			

Table 2: Experimental test conditions

	Inlet Pressure (kPa)	Inlet Temperature (ºC)	Air Inlet Dew Point (ºC)	Inlet Quality (%)	G (kg/m².s)
CO_2	3600	1.4	-	22	188.76
Air	100	26.7	16.2	-	3.34

RESULTS

MODEL VALIDATION

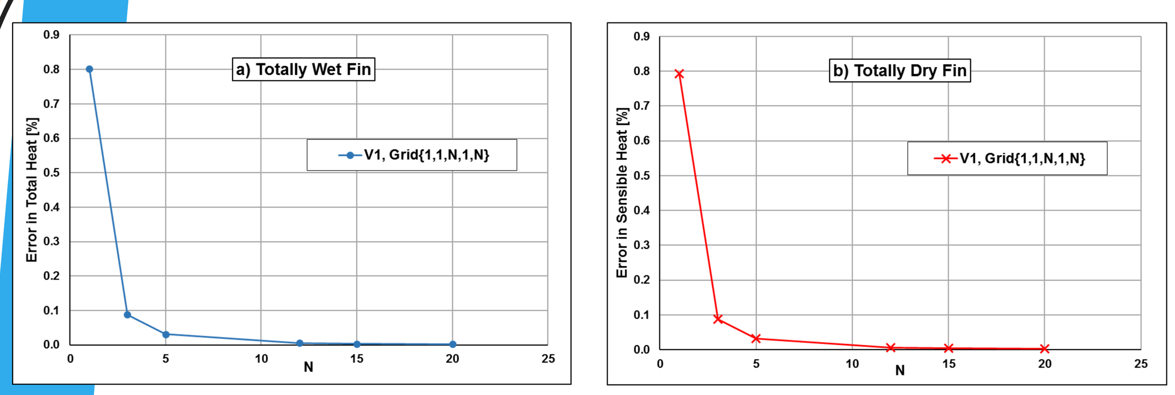

Figure 2: Air side validation; **(a)** totally wet fin, **(b)** totally dry fin

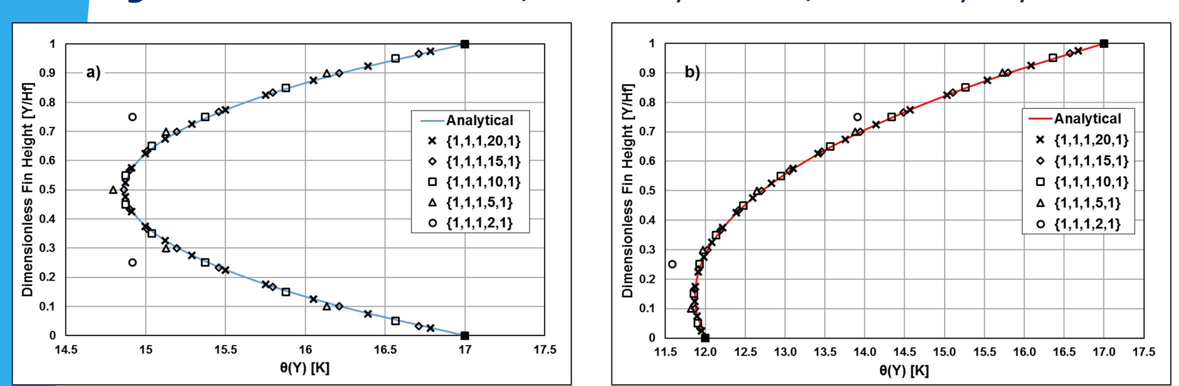

Figure 3: Totally wet fin temperature profile validation; **(a)** $\theta(H_f)=\theta(0)$, **(b)** $\theta(H_f)=\theta(0)+5$ K

CASE(I): FULLY WET TUBE AND FIN

In this case the temperature of the tube was set to 1.4 ºC, Under that condition the mass transfer (due to humidity ratio difference) occurs simultaneously with heat transfer (due to temperature difference) and the whole tube and fin surfaces become totally wet as depicted in Figure (4).

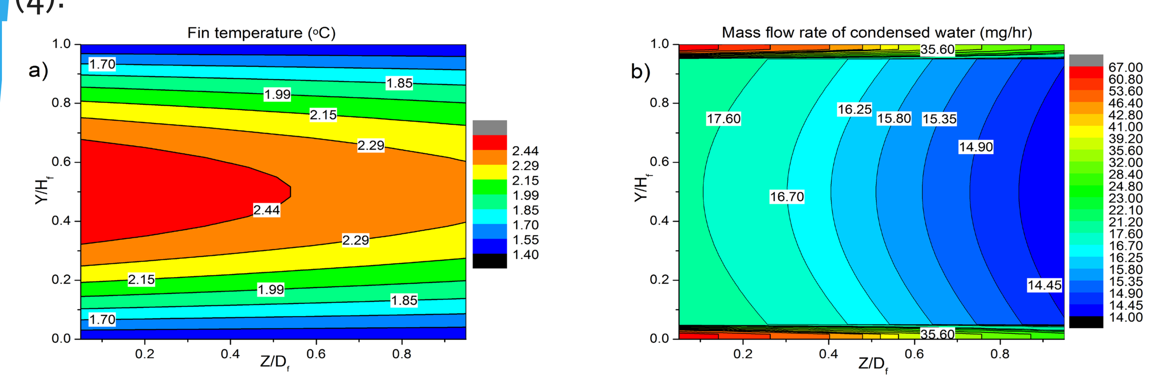

Figure 4: **(a)** fin temperature profile,
(b) mass flow rate of condensed water for case (I)

The deviation in the ε-NTU results based on current model results has been analyzed, taking into account the two common conditions which are used generally to identify the segment status by ε-NTU approach :

- Condition (1): if the average wall temperature (fin and tube) is less than the average dew point of air, then the whole segment will be assumed totally wet, otherwise it will be assumed totally dry.
- Condition (2): if the fin base temperature is less than the average dew point of air, then the whole segment will be assumed totally wet, otherwise it will be assumed totally dry.

Table 3: Deviation in the heat transfer based on numerical results, case (I)

ε-NTU	Segment Condition	Sensible Heat Analysis		Latent heat Analysis		Total Heat Analysis	
		$Q_{sens,num}$ (W)	ΔQ_{sens} (%)	$Q_{lat,num}$ (W)	ΔQ_{lat} (%)	$Q_{tot,num}$ (W)	ΔQ_{tot} (%)
Condition (1) / Condition (2)	Totally Wet	15.86	3.44	11.31	3.62	27.17	3.52

CASE(II): FULLY WET TUBE AND PARTIALLY WET FIN

In this situation the temperature of the tube was kept at 16.1 ºC, which is almost close to the dew point of the inlet air. This scenario leads to a totally wet tube, however, the numerical results have shown that there are some areas on the fin which have a temperature bigger than the average dew point of the corresponding air cells, so sensible heat only is transferred between those areas and surrounding air resulting in a partially wet fin, as illustrated in Figure (5b).

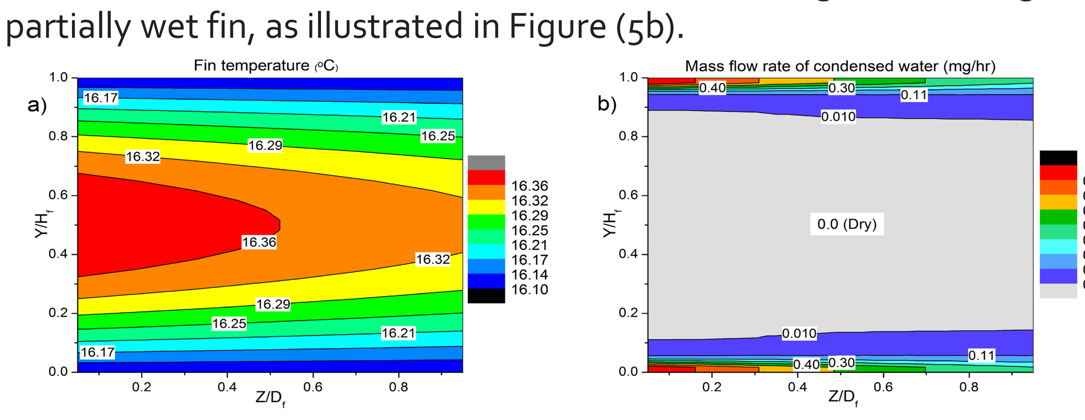

Figure 5: **(a)** fin temperature profile,
(b) mass flow rate of condensed water for case (II)

As seen in Table (4), although ε-NTU methods give two completely different predictions for the segment condition, but finally the deviation in the total heat in both methods is very close.

Table 4: Deviation in the heat transfer based on numerical results, case (II)

ε-NTU	Segment Condition	Sensible Heat Analysis		Latent heat Analysis		Total Heat Analysis	
		$Q_{sens,num}$ (W)	ΔQ_{sens} (%)	$Q_{lat,num}$ (W)	ΔQ_{lat} (%)	$Q_{tot,num}$ (W)	ΔQ_{tot} (%)
Condition (1)	Totally Dry	6.71	3.97	0.03	-	6.74	3.50
Condition (2)	Totally Wet		1.74		369		3.40

CASE(III): FULLY DRY TUBE AND FIN

17 ºC was selected for the tube temperature, which is definitely bigger than the dew point temperature of the inlet air. The whole tube and fin under this condition become totally dry hence there is no mass transfer between the air and the fin and tube surface, only sensible heat transfer occurs.

Table 5: Deviation in the heat transfer based on numerical results, case (III)

ε-NTU	Segment Condition	Sensible Heat Analysis		Latent heat Analysis		Total Heat Analysis	
		$Q_{sens,num}$ (W)	ΔQ_{sens} (%)	$Q_{lat,num}$ (W)	ΔQ_{lat} (%)	$Q_{tot,num}$ (W)	ΔQ_{tot} (%)
Condition (1) / Condition (2)	Totally Dry	6.14	3.97	-	-	6.14	3.97

CONCLUSIONS

- For totally wet fin (case I), the deviations in the latent and sensible heat between ε-NTU method, under both two conditions (condition 1 and 2), and model are very similar. The deviation in the total heat is about 3.52% and mainly due to the assumption of constant air temperature and humidity ratio along the direction between tubes which is usually adopted in the ε-NTU approach and fin theory.
- For partially wet fin (case II), even the ε-NTU methods fail to predict the fin status. However surprisingly, calculating locally (in the model) or globally (in ε-NTU approach) the mass transfer doesn't report big differences in results because of the small weight of the latent heat in this scenario.
- In general, the contribution of latent heat in the total heat deviation is less or at most equals to the sensible heat contribution. That indicates that the main responsible for this deviation between the two approaches is the assumption of no temperature variation of the air along Y-direction which results also to a constant humidity ratio within the same direction. Anyhow, we expect more deviation in results and more contribution of the latent heat for higher inlet relative humidity.

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