HONEYCOMB COMPACT HEAT EXCHANGER FOR COMPRESSOR INTERSTAGE COOLING

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Abstract

The paper presents results of numerical finite volume analysis of an efficiency of honeycomb compact gas to gas heat exchanger used for compressor interstage cooling for aircraft jet engine.

The main analysis starts with building geometry followed by the problem description and model discretization leading to the final results and summary. Eight cases were created for the basic model and also several more for a finned geometry. The parallel and counter-current flow modes were considered Special emphasis was laid on finding the heat transfer rate, LMTD parameter and temperature distribution.

It was found out that a honeycomb structure is almost insensitive for flow arrangement change and that a finned structure assures much higher heat transfer rate. The honeycomb structure is almost insensitive for flow arrangement change while the finned structure turned out to provide a much better heat transfer. The structure is also almost insensitive for a more efficient (i.e. parabolic) fin shape could also increase the heat transfer in the required area. A more accurate mesh should be created to analyse the finned structure and get more reliable results. The honeycomb structure provides a possibility to create the heat transfer process between more then two fluids i.e. three or four.

Keywords: *compact heat exchanger, intercooler, interstage cooling, heat transfer*

1. Introduction

The adiabatic compression process causes the gas (i.e. air) temperature increase. There is also intensive heat transfer through the engine elements whereas the combustion chamber is a main heat source [1, 2, 3]. The higher the air temperature, the lower the air density and compression efficiency. Therefore decreasing compressed air temperature results with the increased air flow in the combustor. Thus it is possible to increase the thrust and engine efficiency.

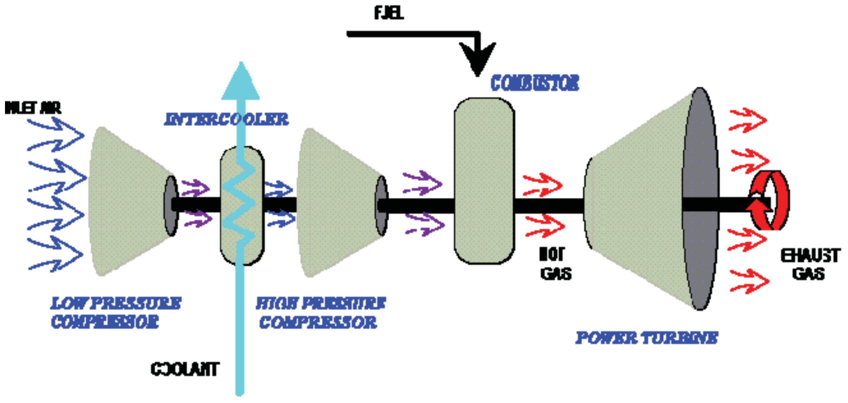

Fig. 1. Gas turbine with the interstage cooling

The developed analysis may lead to obtain higher compression parameter in the aircraft jet engine compressor with interstage cooling.

2. Honeycomb geometry and mesh model

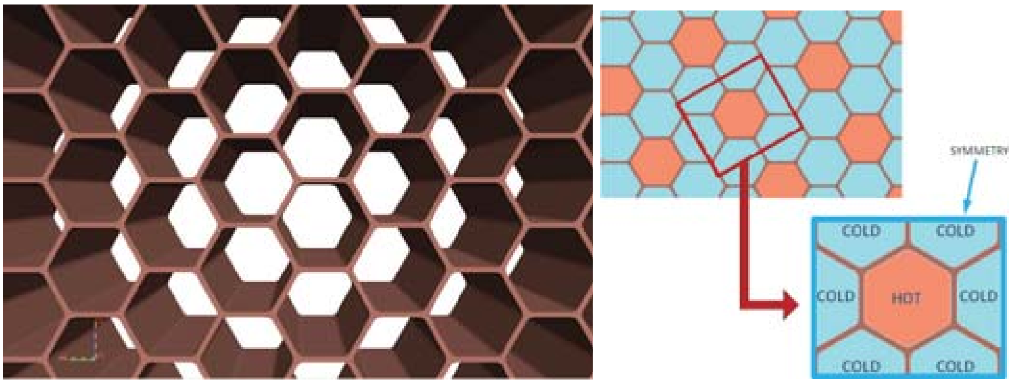

Fig. 1. Honeycomb structure model with an "infinite" number of channels (left) and the model source (right)

One of the advantages of the honeycomb structure, in the context of constructing geometry model, is multiplication possibility. This simplifies the flow calculations to single recurrent configuration. The first idea was to create a model of 24 channels. However advantages of this configuration did not compensate for increased computing time, so it was decided to decrease the amount of channels to six. The geometry was created in the Unigrapics NX 4 environment.

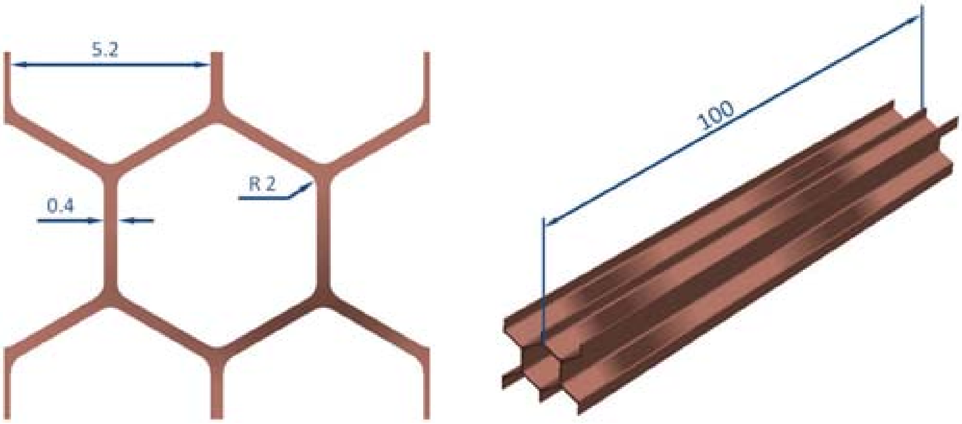

Fig. 2. Model dimensions.

The quasi-regular structure allowed to choose the most appropriate and effective type of elements – 8-node, hexagonal, wedge [4, 5, 6]. The number of elements (333,580) is a compromise between an exact discretization and computational capabilities of available hardware. The NX-made model was exported as a parasolid file to the pre-processor of Fluent package – Gambit. Gambit software was used to create the mesh and specify the boundary conditions.

In all analyse cases all the boundary condition settings were the same, except for the hot channel. Hot channel's configuration plays the key role and different setting was used in each analysed case. Turbulent flow occurs in all channels and the "k-ε" turbulence model was selected. with the hydraulic diameter l (the average diameter of the channel) and turbulence intensity i. The latter parameter was calculated using the equation:

$$i = 0.16 Re^{-\frac{1}{8}} \cdot 100\% , \tag{1}$$

where:

i - turbulence intensity,

Re - Reynolds number.

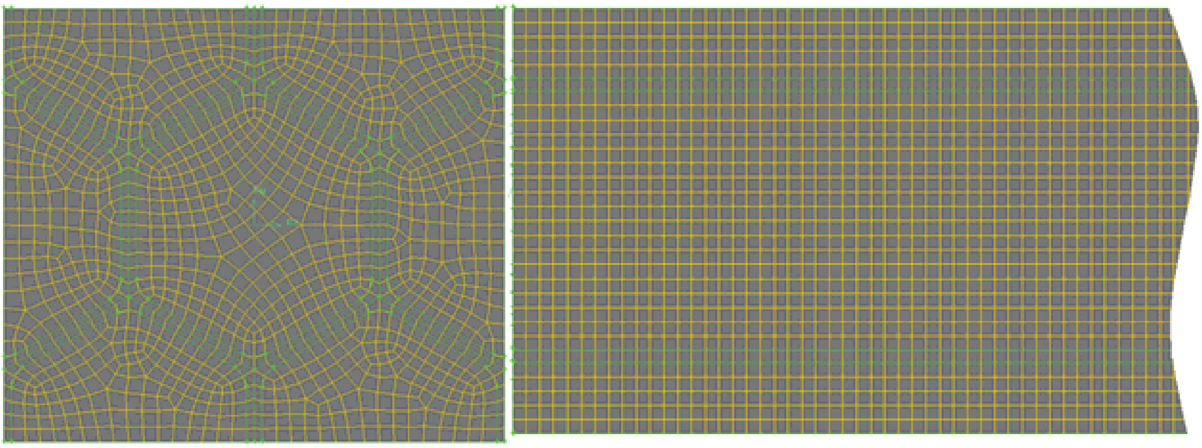

Fig. 3. Front/side view of the model mesh

Tab. 1. The complete boundary conditions specification

Area	Gambit Boundary Condition	Fluent B.C. Specification	Feature
Structure	SOLID	*copper, alloy steel*	*VOLUMES*
Hot Fluid	FLUID	*air*	
Cold Fluid	FLUID	*air*	
Cold Fluid Inlets	MASS FLOW INLET	$\dot{Q} = 0.0002 \frac{kg}{s}$, $T = 280K$, $l = 6\,mm$, $i = 5.9\%$ (each)	*SURFACES*
Hot Fluid Inlet	MASS FLOW INLET	different for each case	
Hot Fluid Outflow	PRESSURE OUTLET	*gauge pressure* = 0	
Cold Fluid Outflows	PRESSURE OUTLET	*gauge pressure* = 0, $l = 6mm$ $i = 5.9\%$ (each)	
Front Structure Surface	WALL	$\dot{Q} = 0$	
Rear Structure Surface	WALL	$\dot{Q} = 0$	
Not Specified Outside Surface	SYMMETRY	-	

4. Results

Calculations were made for 32 cases in the Fluent solver. Parallel flow and counter flow arrangements were considered for both normal honeycomb structure and a finned one. The parameter which was changing during the whole process of analysis was the mass flow rate for the hot channel which is expressed for the particular basic structure case by a dimensionless *k* ratio:

$$k = \frac{\dot{m}_h}{\dot{m}_c}, \qquad (2)$$

where:

$\dot{m}_h$ - mass flow rate for the hot channel,

$\dot{m}_c$ - mass flow rate for single cold channel.

For the finned structure all the boundary conditions were the same as for the default structure except for the mass flow rate for the cold channels, which was decreased to 0.00126 kg/s to keep the same velocity ratio for all channels. The velocity ratio was defined as:

$$w = \frac{V_h}{V_c}, \tag{3}$$

where:

V_h - fluid velocity for the hot channel,

V_c - fluid velocity for the cold channel.

Two materials were used in the analysis for the model structure – copper and alloy steel. The material specification (also for fluid) is shown in the Tab. 2-4.

Tab. 2. Copper material specification

COPPER		
	SYMBOL	VALUE
Density	ρ_c	8978 kg/m^3
Thermal conductivity	λ_c	387.6 W/m^2K
Specific heat (constant pressure)	c_{pc}	381 $J/kg\ K$

Tab. 3. Alloy steel material specification

ALLOY STEEL		
	SYMBOL	VALUE
Density	ρ_c	8030 kg/m^3
Thermal conductivity	λ_c	17 W/m^2K
Specific heat (constant pressure)	c_{pc}	502.5 $J/kg\ K$

Tab. 4. Air specification

AIR		
	SYMBOL	VALUE
Density	ρ_c	1.225 kg/m^3
Thermal conductivity	λ_c	0.0242 W/m^2K
Specific heat (constant pressure)	c_{pc}	1006 $J/kg\ K$

Temperature distributions for parallel and counter flow modes for the copper material are presented in the Fig. 4. and Fig. 5., parallel flow for the alloy steel - Fig. 6. and copper structure with the finned hot channel Fig. 7.

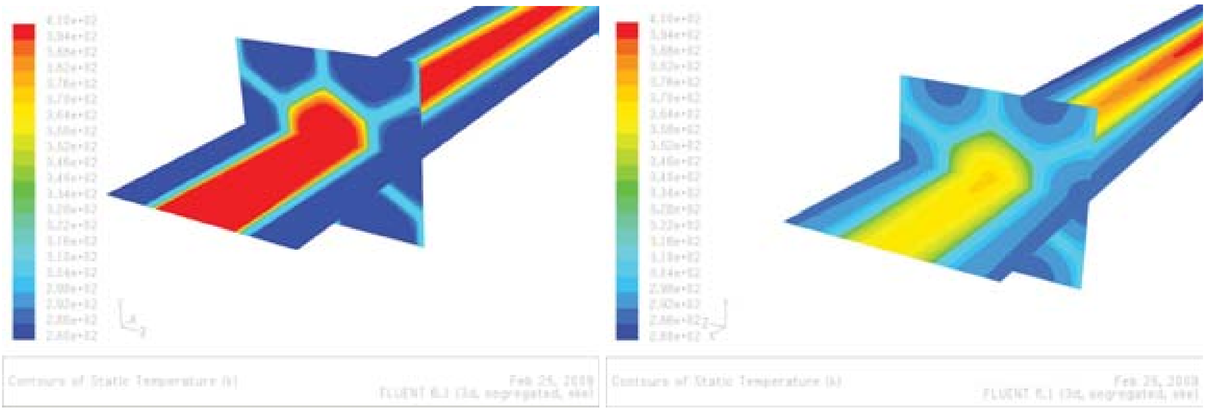

Fig. 4. Section view of temperature distribution [K] at the inlet (left) and outlet side (right) for the k=1 parallel flow (copper material)

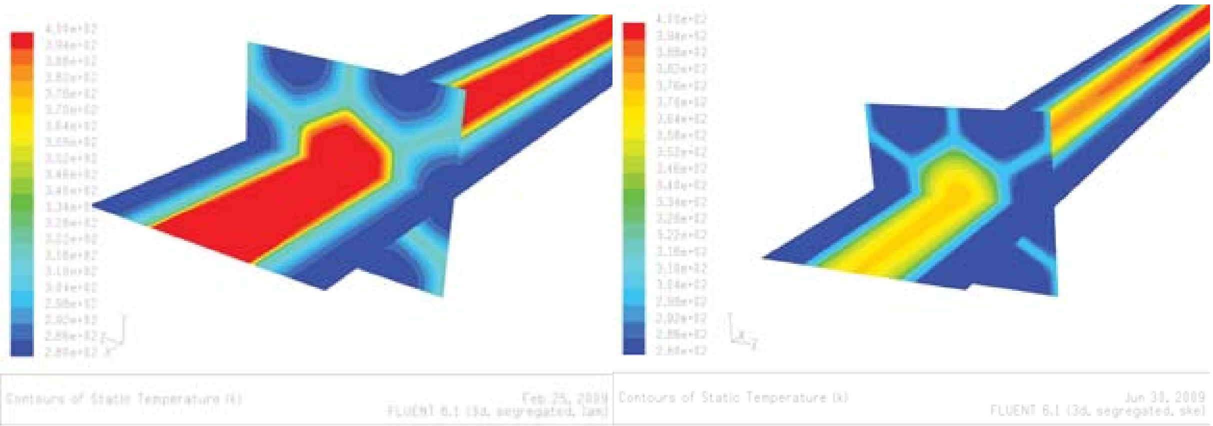

Fig. 5. Section view of temperature distribution [K] at the inlet (left) and outlet side (right) for the k=1 counter flow (copper material)

3. Summary

The first main parameter which can be used to show the heat exchanger effectiveness in a more practical way is the heat transfer rate between the hot and cold channels. The heat transfer rates for all analysed cases are shown in Fig. 8. and Fig. 9.

The log mean temperature difference parameter (LMDT) is another parameter which describes the heat transfer effectiveness. The lower the LMTD, the better is heat exchanger effectiveness. The LMTD parameter is shown in Fig. 10. and Fig. 11.

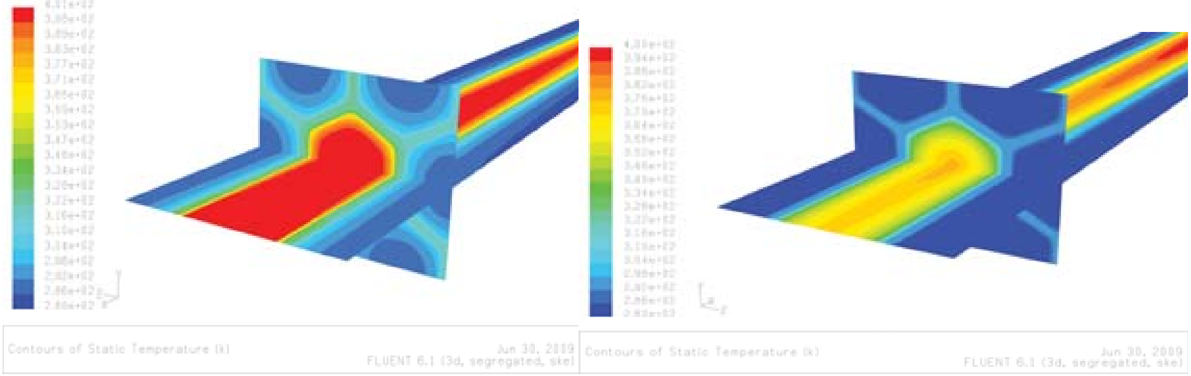

Fig. 6. Section view of temperature distribution [K] at the inlet (left) and outlet side (right) for the k=1 parallel flow (alloy steel material)

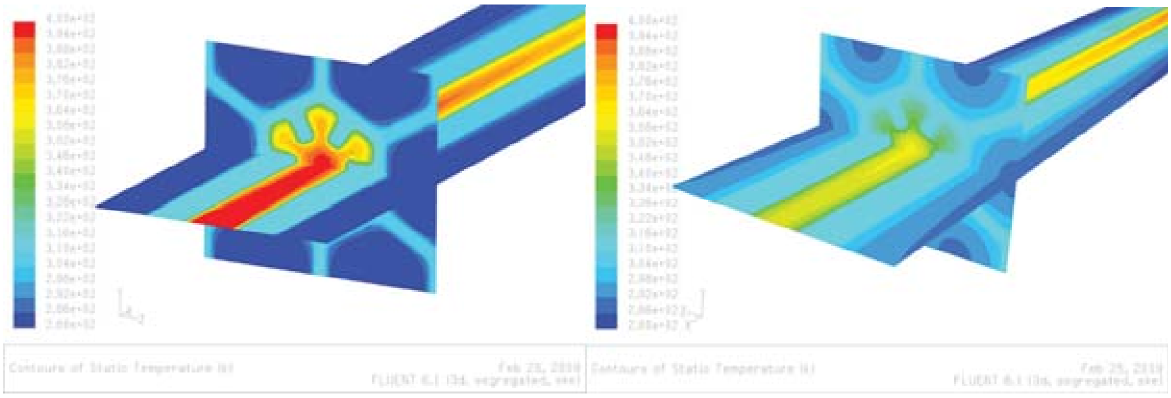

Fig. 7. Section view of temperature distribution [K] at the inlet (left) and outlet side (right) for the k=1 parallel flow with finned hot channel (copper material)

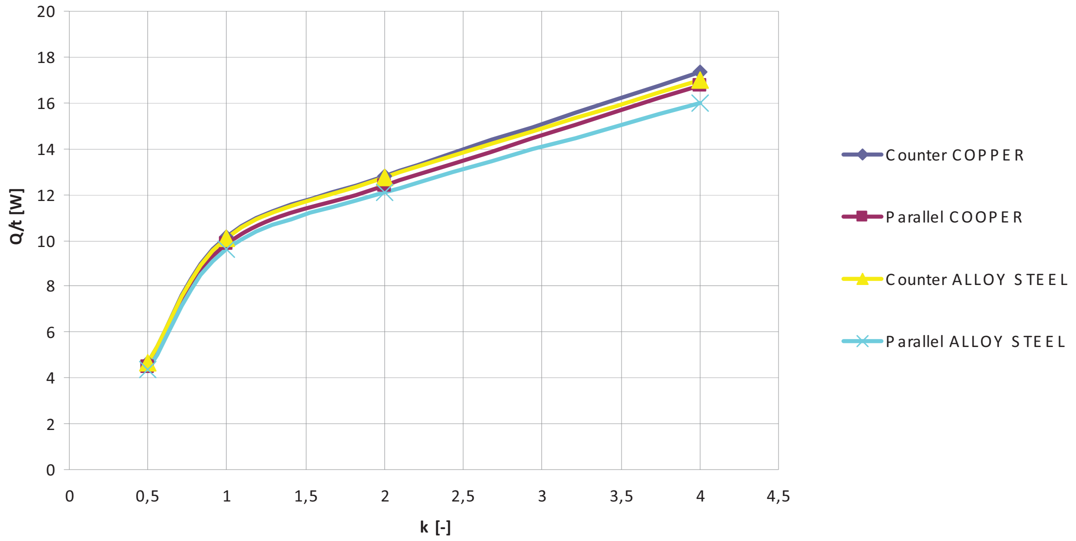

Fig. 8. Heat transfer rates for individual basic analysed cases. For k = 1 mass flow rate $\dot{Q} = 0.0002\,\frac{kg}{s}$

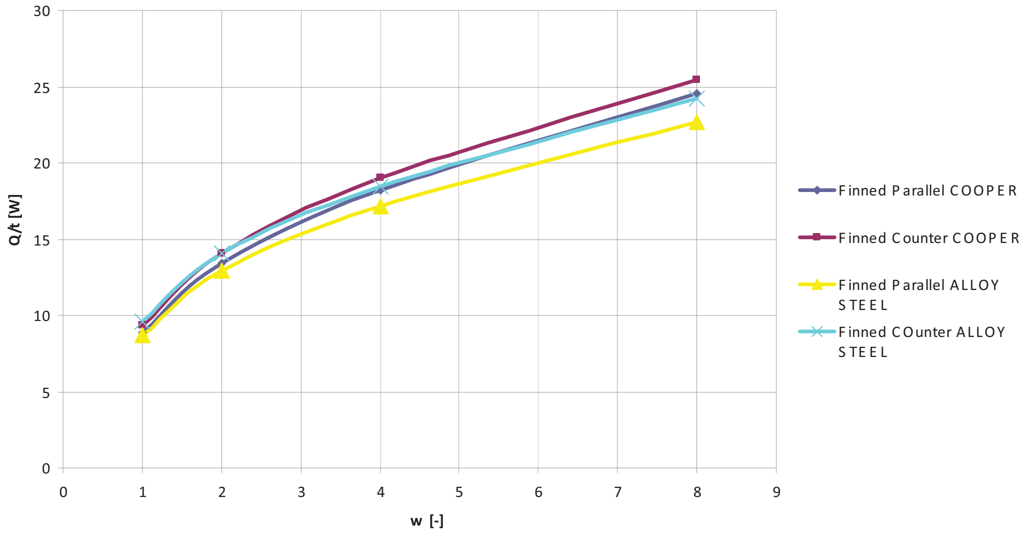

Fig. 9. Heat transfer rate for individual analysed basic cases. For k = 1 mass flow rate $\dot{Q} = 0.00126\,\frac{kg}{s}$

It was found out that the honeycomb structure is almost insensitive for flow arrangement change while the finned structure turned out to provide a much better heat transfer. The structure is also almost insensitive for a more efficient (i.e. parabolic) fin shape could also increase the heat transfer in the required area. However a more accurate mesh should be created to analyse the finned structure and get more reliable results. Also the honeycomb structure provides a possibility to create the heat transfer process between more then two fluids i.e. three or four.

Some more improvements could involve:

- different arrangement for hot and cold channels,
- use of material with a higher thermal conductivity factor for the structure and fluids,
- addition of fins to the solid structure to increase the heat transfer between the channels,
- creation of the mesh which contains more elements,
- setting the Fluent solver into double precision calculations mode,
- use of different fluids for the hot and cold channels,
- boundary condition velocity for channels inlet should be expressed as a function of the channel diameter.

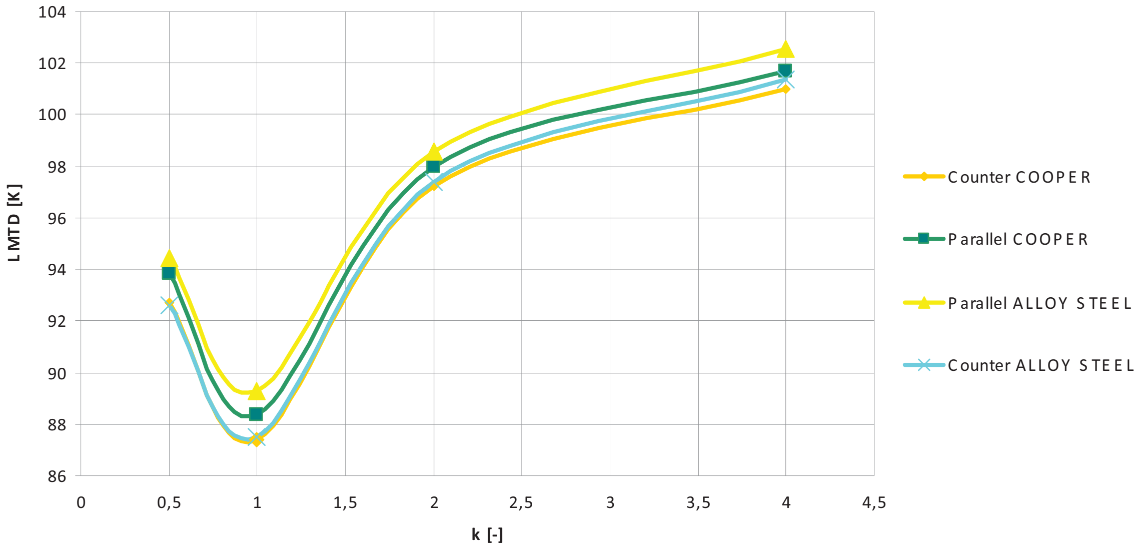

Fig. 10. LMTD parameter for individual basic analysed cases

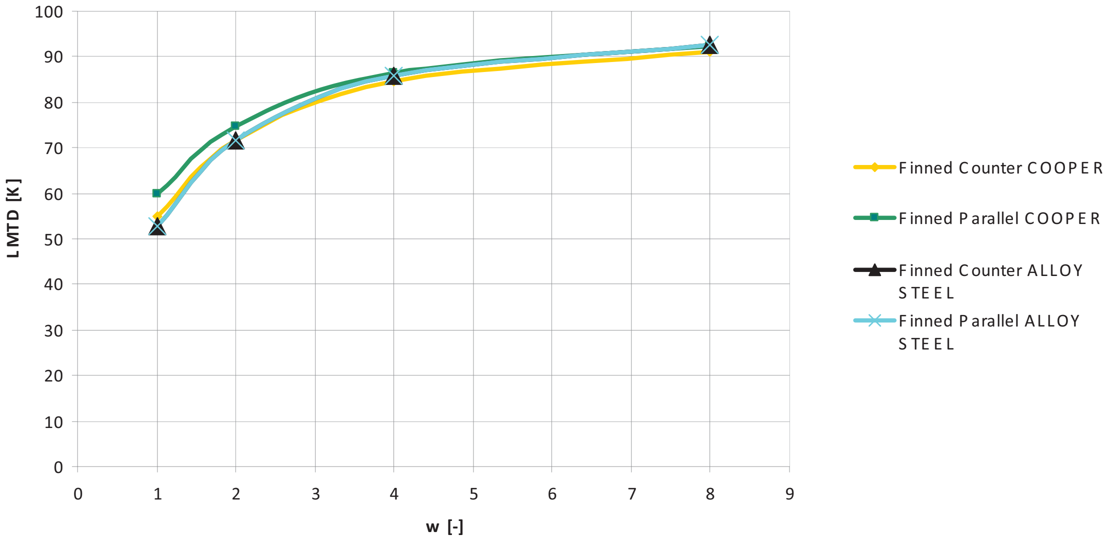

Fig. 11. LMTD parameter for the finned model cases

Most of these improvements are fully practicable and can be a subject of further analysis, however some of them, like mesh congestion, would require high computational capability.

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