

Experimental Investigation of Heat Transfer Rate and Pressure Drop through Angled Compact Heat Exchangers Relative to the Incoming Airflow

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ABSTRACT

This paper presents pressure drops and heat transfer rates for compact heat exchangers, where the heat exchangers are angled 90°, 60°, 30° and 10° relative to the incoming airflow. The investigation is based on three heat exchangers with thicknesses of 19mm and 52mm. Each heat exchanger was mounted in a duct, where it was tested for thermal and isothermal conditions. The inlet temperature of the coolant was defined to two temperatures; ambient temperature and 90°C. For the ambient cases the coolant had the same temperature as the surrounding air, these tests were performed for five airflow rates. When the coolant had a temperature of 90°C a combination of five coolant flow rates and five airflow rates were tested. The test set-up was defined as having a constant cross-section area for 90°, 60° and 30° angles, resulting in a larger core area and a lower airspeed through the core, for a more inclined heat exchanger.

The investigation showed that a more inclined heat exchanger resulted in lower static pressure drop and at the same time achieved a higher heat transfer rate, for a specific mass airflow rate. This result was obtained for all three heat exchangers. When analysing the parameters at the same core speed it was seen that the static pressure drop was increased for the 10° and the 30° angled heat exchangers, compared to the 90° configuration. For the 60° cases the pressure drop was both increased and decreased compared to the 90° cases, depending on the heat exchanger design. It was also seen that the pressure drop and the heat transfer rate variation were negligible between the downflow and crossflow orientation of the heat exchanger. When defining the static pressure drop to 200Pa either a 19mm thick heat exchanger at 60° or a 52mm heat exchanger at 90° can be used to obtain the same heat transfer rate.

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INTRODUCTION

The cooling demand for heavy-duty trucks has increased in recent years, along with emissions regulations and market requirements; and is likely to continue increasing. This is also a result of increased engine power together with additional heat sources, such as Exhaust Gas Recirculation, Charge Air Cooler and Waste Heat Recovery. To be able to meet upcoming emissions regulations and market requirements, additional systems will be required and a further increase in

cooling demand will be seen. To fulfil the cooling demand, enlarged heat exchangers, multiple heat exchangers or higher heat transfer efficiency are required. In cab-over-engine trucks, the front under-run protection, the cab floor and the main frame, limit the area available for heat exchangers in the front part of the vehicle; together with the tipping function of the cab. This forces the vehicle manufacturers to evaluate other locations for the heat exchangers. A common factor for most of these positions is that the incoming cooling airflow is not

perpendicular to the heat exchanger, as is the case for heat exchangers mounted at the front. It is therefore necessary to investigate the airflow behaviour when the air is angled relative to the heat exchanger, as well as how the heat transfer and pressure drop are affected.

There are vehicles today that have the heat exchanger located where the airflow is not necessarily perpendicular. For example some busses have their air intake positioned on the roof or at the side of the vehicle. Alternative cooling module positions have been investigated by, [1,2,3,4] for example. The aerodynamic resistance of the vehicle must also be taken into consideration with new cooling module positions, since they affect the airflow around the vehicle; and the aerodynamic drag increases by the square of the vehicle velocity, becoming dominant above 80km/h for heavy vehicles [5]. Earlier investigations regarding angled heat exchangers and airflow characteristics through a heat exchanger have also been carried out, for example [6,7,8]. M Kim et al [6] performed experiments regarding angled heat exchangers where the exposed core area was constant for each angle, described in Case B in Figure 1. The results from that study were that heat transfer rate was not significantly affected and the pressure drop over the installation increased when increasing the angle of the heat exchanger.

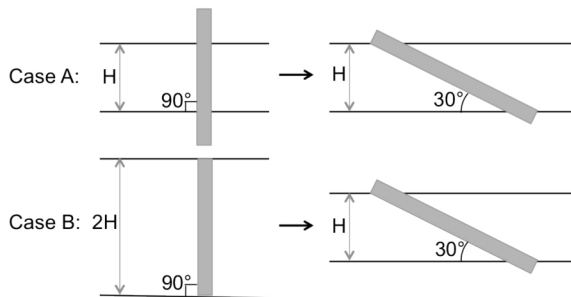


Figure 1. Definition of test set-ups.

An early investigation carried out by M Nicholds at NACA [7], presented pressure drop data for angled heat exchangers relative to the airflow. The study was based on method Case B in Figure 1. The results showed that the flow losses increased only slightly for angles between 30°-80° compared to the perpendicular case, where the tests were carried out at 10° intervals from 10° to 90°. For an inclination larger than 30° the pressure loss increased drastically. At 30° the airflow over the heat exchanger was fairly uniform as well. An investigation regarding angled heat exchangers for a Grand Prix racing car was performed by D Rivers et al [8]. The tests were performed for a given duct size, Case A. The conclusion from this work was that the pressure drop was decreased for the angles 35° and 45°, where the tested angles were 90°, 75°, 57.5°, 45° and 35°. The 35° configuration was the most inclined heat exchanger that was tested. For angles less inclined than 45° (57.5° and 75°) the pressure drop was increased compared to the 90° case. It was also observed that the heat transfer rate followed the same behaviour with a low value for angles of 57.5° and 75°, and higher values for angles of 35° and 45°.

Though, it should be noted that the core area is doubled for the 30° angle and the velocity through the heat exchanger is halved compared to the 90° case.

This article presents results for part of a larger project, involving experiments, 3D Computational Fluid Dynamics (CFD) and 1D simulations. The simulations are carried out for the complete experimental set-up as well as for one period of a louvered fin of the heat exchanger. The latter case is carried out to be able to understand the airflow behaviour when the heat exchanger is angled. Previous results are performed by L Henriksson et al and are presented in [9,10,11]. The first article [9] focuses on comparing pressure drop over the heat exchanger, for 90° and 30°, obtained from CFD simulations and experiments. Conclusions were that CFD over predicted the pressure drop and the deviation was a maximum of 6-8%. It was also shown that there should not be a duct mounted behind the heat exchanger when it is angled. The reason being that it creates a large resistance and the results are no longer only dependent on the heat exchanger and its angle. The second article [10] presents a CFD method to simulate the airflow within the core of the heat exchanger. Detailed airflow characteristics within the core, when the heat exchanger was simulated at different angles, are also presented. The third article [11] presents experimental results where focus is on the crossflow cases, see definition in chapter *Experimental Set-up*. Conclusions from the third article were that the more inclined heat exchangers resulted in a lower static pressure drops and at the same time achieved higher heat transfer rates, at a specific mass airflow rate.

This article can be seen as a part-two investigation, to the previous article [11]. It is focused on downflow experiments, while the previous article was focused on crossflow experiments. A comparison between the downflow and the crossflow cases will also be included in this article. The main purpose with the present investigation was to evaluate experimental results, both static pressure drop and heat transfer rate. Three heat exchanger designs were evaluated with the airflow perpendicular relative to the heat exchanger: 90°; and with an angle of 60°, 30° and 10°. The test section area was defined to be constant, corresponding to Case A in Figure 1. This is the most suitable method when there is a given space available on the vehicle. It should be kept in mind that there would be a larger core area, exposed to the oncoming airflow, for the more inclined cases.

CASE DEFINITION

A compact heat exchanger has a large surface area to increase the heat transfer between the liquid and the cooling air. A crossflow compact louvered heat exchanger consists of flat tubes through which the liquid flows, and louvered fins where the air passes through, see Figure 2. Louvered fins are used in order to break up the boundary layer, increasing the heat transfer rate. Figure 2 illustrates a 10mm thick heat exchanger geometry.



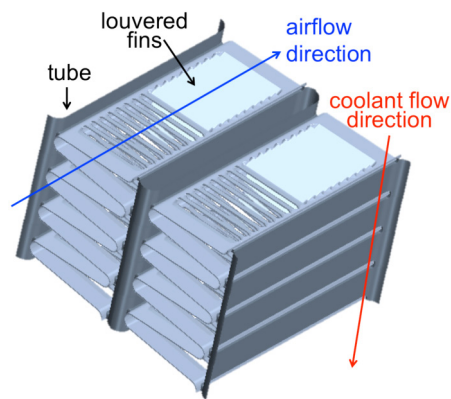


Figure 2. CAD geometry of a 19mm thick heat exchanger, together with the flow directions.

Heat Exchanger Geometries

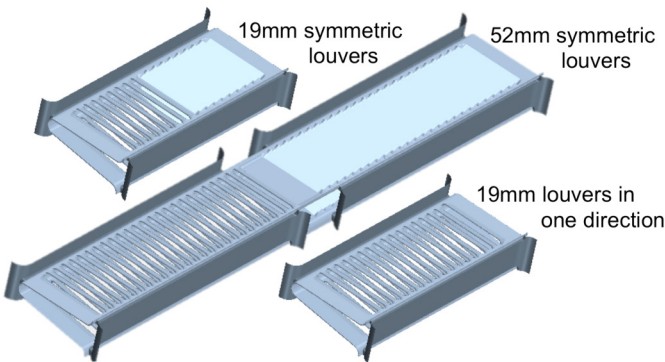
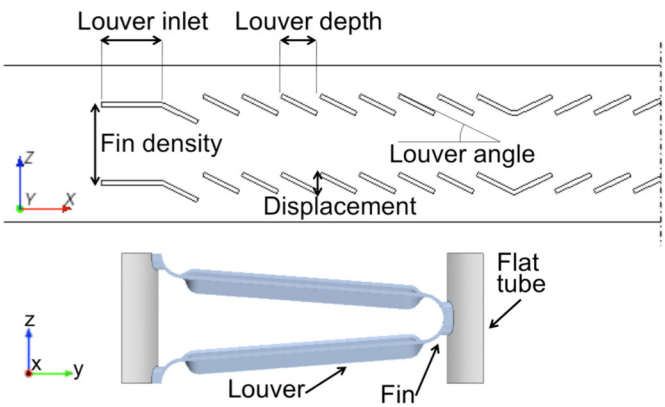


Figure 3. CAD geometry of all three heat exchangers.



Parameter:	All Cases:
Displacement	0.4 mm
Fin density	1.8 mm (14 fins/inch)
Louver angle	26°
Louver depth	0.9 mm
Louver inlet	1.4 mm
Tube outer thickness	2 mm

Figure 4. Definition of parameters for the investigated louvered fin heat exchangers.

For the experiments three specially made compact heat exchangers were manufactured with a frontal core area of 888×888mm. This article will present the results from all three heat exchangers, included in this investigation. Two of the heat exchangers had a thickness of 19mm, one with symmetrical louvers and one with the louvers in one direction, asymmetric louvers. The third heat exchanger had a thickness of 52mm and had symmetric louvers. In Figure 3 one period of a louvered fin for each heat exchanger is shown.

A louvered fin compact heat exchanger is defined by a number of parameters. These are described and presented in Figure 4, for the investigated heat exchangers. A part of a louvered fin is also shown in the figure.

Experimental Set-Up

The experiments were performed at the radiator supplier, where a test set-up was built to test each heat exchanger and angle. They were tested in two directions: the coolant tanks were at the sides of the heat exchanger resulting in a horizontal flow of the coolant; for the other set-up the heat exchangers were rotated 90°, resulting in a vertical flow of the coolant, since the tanks were then at the top and at the bottom. The first scenario is defined as crossflow tests and the second scenario is defined as downflow tests, see Figure 5. The heat exchangers were thereafter angled downwards. It is the results from the downflow orientations as well as a comparison with the crossflow orientations that are presented in this article.

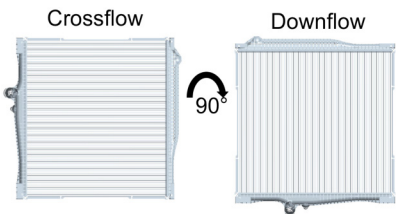


Figure 5. Definition of crossflow and downflow orientation.

Each heat exchanger was tested at an angle of 90°, 60°, 30° and 10°, relative to the airflow. The heat exchangers were mounted within a duct, which had a constant width of 668mm for all configurations. The height varied and for the 90° 60°