PIV MEASUREMENT AND NUMERICAL ANALYSIS OF A NEW REFRIGERATION COMPARTMENT OF THE REFRIGERATOR

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A new cooling duct system was developed in order to increase the refrigerator performance in terms of uniform temperature distribution particle image velocimetry (PIV) and the commercial software FLUENT were used to compare the performance of the conventional cooling system with the new cooling system. The new cooling system effectively cooled the door basket region, thus increasing the uniformity of the temperature distribution in the refrigeration compartment.

KEYWORDS**: PIV Measurement, Numerical Analysis, Refrigerator**

INTRODUCTION

Recent studies on refrigerators focus on increasing the performance in terms of energy consumption and noise reduction. A thorough investigation of the flow inside the refrigerator is needed in order to achieve such goals[1]. Experimental and numerical analysis methods were employed to investigate the flow inside the refrigerator. The side by side type refrigerators use a single evaporator, and a single fan to cool the freezer and refrigerator compartments. The high-temperature, high-pressure refrigerant flows through the evaporator, cooling the surrounding in the process, and the cool air is distributed into the freezer and refrigerator compartments according to a prescribed volume ratio. The cool air flowing into the refrigeration compartment passes through the damper insulation and out of front and rear outlets. Once the refrigeration compartment is cooled to a prescribed temperature, the temperature is controlled by the opening and closing of the damper door, located inside the damper insulation. In this refrigeration cooling system, the upper shelf in the refrigeration compartment is over-cooled, while the lower shelf and door basket regions are under-cooled, resulting in non-uniform cooling of the refrigeration compartment. Consequently, in order to induce a uniform temperature distribution inside the refrigeration compartment, ducts were installed from the damper insulation leading to outlets installed on the left and right walls of the compartment, near the lower shelf and lower door baskets. Two-dimensional PIV measurements were carried out at the shelf regions and door basket regions inside the refrigeration compartment. Also, in order to analyze the velocity and temperature distribution inside the whole refrigeration compartment, the commercial software FLUENT was used for the numerical analysis of the conventional duct system and the new duct system of the refrigerator.

PIV MEASUREMENTS

For the comparison of the conventional duct system and the new duct system of the refrigerator, the PIV system as shown in Fig. 1 was used to measure the velocity distribution in each shelf and door basket. The PIV system consists of a 2-head Nd:YAG laser (max. 300 mJ/7ns pulse), light sheet forming optics, a laser arm to direct the light source, a pulse synchronizer, and a 1K×1K CCD camera (30 frames/sec). Lubricating oil (Glycerin, SG-α 10G) was used with an atomizer to supply the seeding particles. Field-of-views of 120mm by 120mm were used to capture 50 particle images and calculate the mean velocity field.

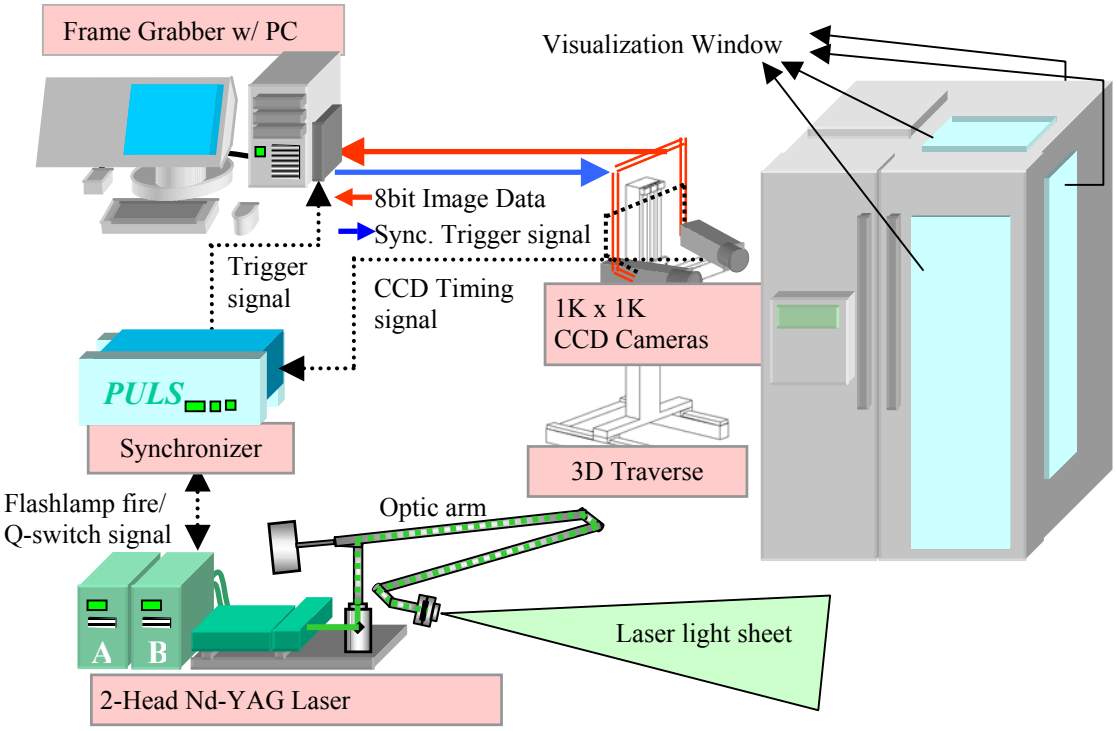
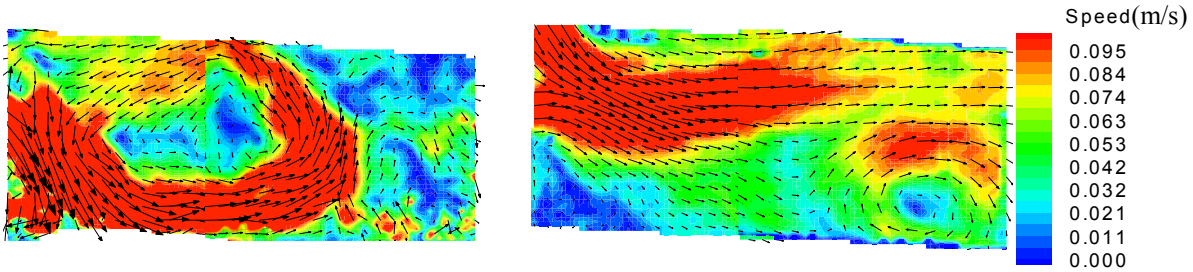


Fig1. Schematics of the PIV measurement system

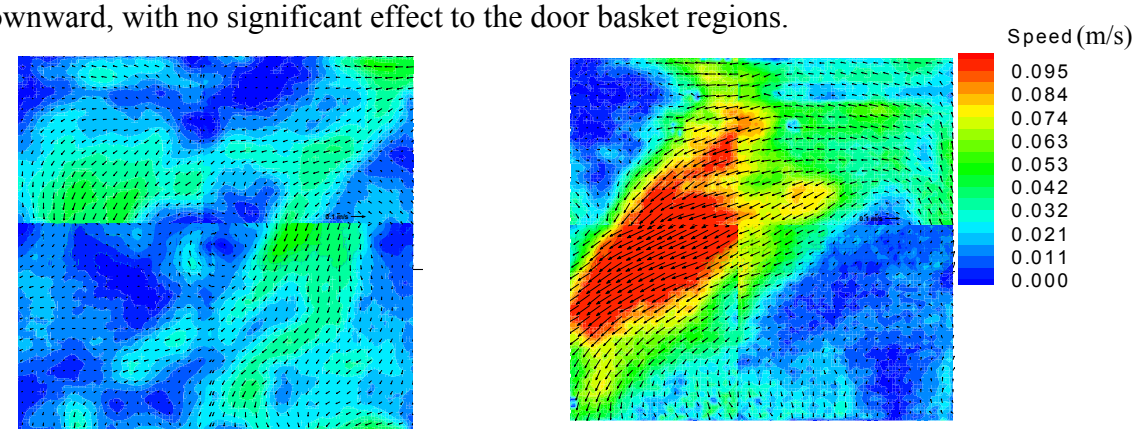
The mean velocity field results of the upper shelf of the refrigeration compartment with the conventional duct system and with the new duct system are compared in Fig. 2. It can be seen that the flow induced by the conventional duct system and the new duct system show similar patterns. The flow in the upper shelf region of the two cooling systems were found to wrap around the tip of the upper shelf to reach the lower shelf regions, and forming a vortex flow in the rear wall region with the flow originating from the rear outlet in the refrigeration compartment. The flow in the lower shelf regions showed a significantly lower velocity and no noticeable flow characteristics were found. In the lower-most shelf region, the cooling flow was found to flow along the rear wall in the downward direction and after reaching the lower-most horizontal surface, changing direction and flowing toward the door baskets. From these similar flow characteristics the two duct systems could be anticipated to show similar performance in the cooling of the shelf region.



(a) (b)

Fig2. Mean velocity distribution of the upper shelf of the refrigeration compartment
(a) conventional cooling system (b) the new cooling system

The mean velocity field results of the basket regions with the conventional duct system and with the new duct system are shown in Fig. 3. Due to the new duct system, the flow into the lower basket can be observed, and it was found to efficiently cool the region; effectively leading to a more uniform temperature distribution inside the refrigerator compartment. The relatively high-speed flow from the right outlet was found to reach the center region of the door basket, and the relatively low-speed flow from the left outlet was found to flow along the left wall downward, with no significant effect to the door basket regions.



(a) (b)

Fig3. Mean velocity distribution of the door basket region of the refrigeration compartment
(a) the conventional cooling system (b) the new cooling system

NUMERICAL SIMULATION

The numerical analysis of the velocity and temperature distribution inside the refrigeration compartment was carried out using the commercial software FLUENT. The structured grid system (grid number: 320,000) was made with the body fitted coordinate, with the boundary condition taken as the average heat transfer coefficient calculated with a 30°C surrounding. The left wall is adjacent to the -18°C freezer compartment and the boundary condition was set according to its average heat transfer coefficient. The outlet velocity and temperature at each outlet were set as found by experiments. The standard k-ε model was used as the turbulence model[2]. Figure 4 shows the velocity distribution at the center plane of the refrigeration compartment and temperature distribution at the wall of the refrigeration compartment with the new cooling duct system. A cooling flow is observed in Fig. 4a, only in the home-bar and lower door basket region, while other door basket regions do not show any significant cooling flow.

The upper wall outlets are directed perpendicular to the wall surface while the lower wall outlets are directed 45° downward compared to the wall surface. The lower wall outlets are tilted 45° downward in order to increase the flow rate into the door baskets, and improve the cooling rate of the region, thus inducing a more uniform temperature distribution. As can be seen in Fig. 4b the heat is transferred out of the refrigeration compartment through the wall located adjacent to the freezer compartment, and transferred into the compartment through other walls. Also the refrigeration compartment is cooled mainly by the outlets located at various locations. This result suggests that the new duct system exhibits an improved uniform cooling performance of the refrigerator.

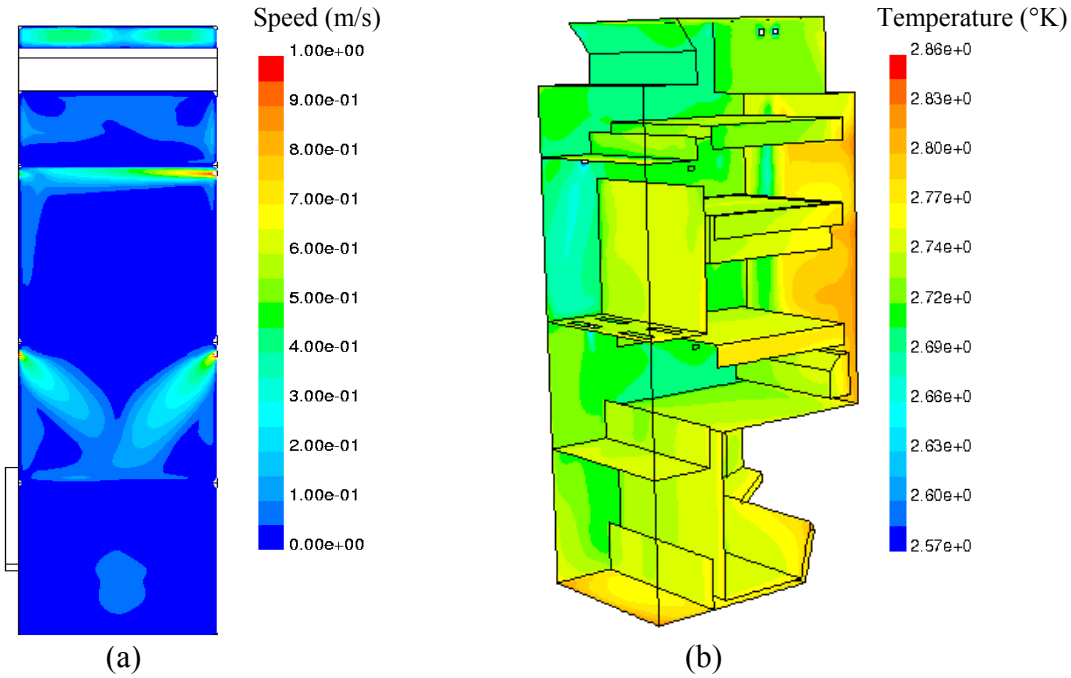


Fig 4. (a) The velocity distribution at the outlet plane of the refrigeration compartment, (b) The temperature distribution at the wall of the refrigeration compartment

SUMMARY

The PIV technique and FLUENT were used to analyze the flows inside the refrigeration compartment in the conventional cooling duct system and in the new cooling duct system. An overall uniform temperature distribution was successfully achieved by installing additional ducts inside the left and right walls of the compartment, leading cooled air to flow toward the lower door basket.

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