Abstract

The study aims at investigating the fluidic and thermal fields at the vertical section of a 23-inch commercial TFT-LCD TV panel through both numerical simulation and experimental validation. Twelve cold cathode fluorescent lamps (CCFLs) of backlight module of TFT-LCD panel are located in the vertical-trapezium enclosure space from top to down. The CCFLs heat up ambient air by heat conduction and form plume flow by buoyancy and gravity. Because of these CCFLs’ influence, natural convection phenomenon exits in the backlight module. The simulation of temperature distribution for transient and steady state is done with conditions of two dimensional laminar flow and incompressible properties in the natural convection. Subsequently, the temperature distribution on the TV panel is compared via heat conduction.

The study conducts a reliable verification process. The transient temperature distribution in the direct-type backlight module and LCD panel is measured by K-type thermocouples. Based on the measurement, the buoyancy effect and flow field influence the direct-type backlight module are further discussed.

Keywords: CFD, Natural convection, Enclosure, TFT-LCD TV, Cell flow

1. Introduction

Natural convection (or free convection) is caused by the change of air density that leads to air flow by buoyancy. Fluid near a vertical thermal plate flows upward due to heating effect. This is called exterior natural convection. Observing the behavior of fluid in concentric cylinders by interferometer, the inner flowing fluid goes upward to contact the outside cylinder and then pours out. This is called inner convection phenomenon [1].

Natural convection phenomenon in an enclosure space can be divided into two parts. It depends on the directions of the gradient density variation, vertical and horizontal. For gradient density varying in two directions, fluid starts flowing while the gradient is steep enough. In an enclosure space, Nansteel and Greif [2-3] discovered inner partition plates cause recirculation zones which reduce heat transfer effect. Lin and Bejan [4] used water as fluid to investigate natural convection with partition plates in an enclosure space. They concluded that the size of open holes influences the pattern of heat conduction and flow shape. Additionally, many researchers studied natural convection effect in an enclosure container by analytic methods. [5-10] They changed the Rayleigh number in the enclosure box which has partition plates to calculate and analyze the natural convection phenomenon. Flow phenomenon depending on geometry and heating condition has a specially flow shape and heat conduction characteristic.

Because FEM is suitable for dealing with complicated geometry and general use, it is gradually applied to solve the field question such as thermal-fluidic.

The study investigates the fluidic and thermal fields in the vertical section of a 23-inch commercial TFT-LCD TV panel with a direct-type backlight module. The space inside a direct-type backlight module is a vertical trapezoid enclosure with air. Twelve CCFLs in the backlight module are parallel each other to the ground plane. Heat generated from the CCFLs causes natural convection in the direct-type backlight module. After a long term lighting, heat conducts to all structural components to increase the temperature of the TV panel.

The study conducts a reliable verification process by CFD and heat conduction based on FEM. This paper presents two dimensional transient analysis in laminar and incompressible flow of the backlight module, including the temperature, velocity, and density distribution. Computed temperature distribution using the ANSYS/Flotran module is further employed as boundary conditions in subsequent thermal analysis using the ANSYS thermal module. Subsequently, thermal conduction in the panel is analyzed via the ANSYS thermal module. The transient temperature in the direct-type backlight module and the LCD panel is measured by K-type thermocouples. Based on measurement, the buoyancy effect and flow field influencing each direct-type backlight module are further discussed.

In normal operation, twelve CCFLs emit thermal energy steadily in the TFT-LCD TV module. Thermal energy transfers through heat convection in the cavity and conduction via structural components. In the study the simulation combining the CFD and heat conduction computation is performed to investigate the temperature change and distribution on the TFT-LCD TV panel.

The aim of this study is to develop a procedure utilizing the FEM analysis and experimental measurement to assist engineers to design, analyze, and test the LCD-TVs. Thus the developed technique can enhance the research and development of Flat Panel Display industry.

2. Thermal Loading of TFT-LCD TV

Figure.1 illustrates the energy balance of CCFLs, courtesy of Harison Toshiba Lighting Corporation. There exists 26.7% heat loss from electric power for a single CCFL. The electric power for a single CCFL is 4.8 W, and its diameter and length are 3mm and 478mm, respectively.

For considering the temperature distribution in the central cross section, the electrode heat loss is not taken into account. Assuming heat is generated form 80% energy of CCFLs, then the heat flux in a unit length of CCFL can be expressed by

\[
\frac{4.8W \times 26.7\% \times 80\%}{2\pi \times 0.0015m \times 1m} = 108.7 \frac{w}{m^2}.
\]

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3. Numerical Analysis

The numerical analysis tool, ANSYS/Flotran, follows the laws of mass continuity, momentum conservation and energy conservation to calculate velocity, pressure and temperature distribution. Structural quadrilateral elements are used in modeling. Figure 2 charts the flow diagram of CFD and structure-heat-conduction analysis.

3.1 Assumed Condition

In the analysis, two dimension transient, laminar flow, incompressible flow, Newton fluid, buoyancy effect in the field of gravity are considered, but heat radiant and surface coarse are neglected. Physical properties of air at 64°C including density(\(\rho\)), specific heat, heat conduction coefficient and viscosity coefficient(\(\mu\)) are \(1.06 \text{ kg/m}^3\), \(1005 \text{ J/kg}^\circ\text{C}\), \(0.0258 \text{ W/kg}^\circ\text{C}\) and \(1.99 \times 10^{-5} \text{ N} \cdot \text{S/m}^2\), respectively.

The Reynolds number is 31.6 in the direct-type backlight module as shown in Eq.(1). The thickness (\(l\)) in the direct-type backlight module is 18mm. The Mach number is smaller than 0.3 (Eq.2) since fluid is incompressible.

\[
\text{Re}_{\text{Backlight Module}} = \frac{\rho vl}{\mu} = \frac{1.06 \times 0.033 \times 0.018}{1.99 \times 10^{-5}} = 31.6
\]

\[
M_{\text{Backlight Module}} = \frac{v}{a} = \frac{0.033}{340} = 9.7 \times 10^{-5}
\]

3.2 Physical Model Establishment

The air layer in the backlight module is meshed with 14221 elements. The elements ambient CCFLs are meshed finer due to evident change of computed physical quantities as shown in Fig.3.

3.3 Governing Equation and Boundary Condition

It is assume that air-flow velocity at the top, down, left and right side of the inner cavity of backlight module, and surrounding CCFLs is zero (Eq.3).

\[
u = v = 0
\]

Based upon above assumptions, flow and temperature fields can be described by following governing equations. The conservation of mass and momentum can be expressed by the continuity of mass (Eq.4) and Navier-Stokes equation (Eq.5), respectively.

\[
\nabla \cdot \nu = 0
\]

\[
\frac{\partial \nu}{\partial t} + \nabla \cdot (\nu \nu) = -\frac{1}{\rho} \nabla P + \nabla \cdot (\mu \nabla \nu)
\]

4. Experimentation

For the experimentation task a TFT-LCD TV temperature measuring system is set up, as shown in Fig.4, using K-type thermocouples with reliable temperature ranging from -60°C to 175°C, and less than 0.5°C acquiring error.
A 12-bit DAQ Card is used to sample and store acquired data in a host PC, and a LabVIEW human-machine interface is coded for the measurement task.

Figure 5 shows the locations for temperature measurement, where nine points (T0-T8) are in the direct-type backlight module and three points (T9-T11) are on the LCD panel. The ambient temperature at the laboratory is 27°C.

5. Comparison of Numerical Analysis and Experiments

5.1 Temperature Distribution in the Backlight Module

Figure 6 shows the computed steady state temperature distribution in the backlight module of TFT-LCD TV panel. It is noted that the upper portion of backlight module is an apparent temperature raising region due to natural convection. Figure 7 characterizes transient temperature at different locations in the backlight module for both computed and measured results. They are rather comparable.

More precisely, the steady state temperature on the surface of CCFL is around 60°C obtained form both experimental and simulation results. For the other measuring points except T8, the difference percentages are smaller than 8%. As to T8, the difference between simulation and measurement is 13.4%.

The reason is the density is changing low when hot air in upper portion of the backlight module is heated by the CCFL. Higher-density air concentrates near the diffuser plate and circulates slower in the backlight module than other portions.

It is worth mentioning that in the study heat arising form electrode loss is neglected. This may cause errors between numerical simulation and experimental results.
5.2 Discussions on a Single CCFL

Figure 8 shows the temperature distribution surrounding the 2nd CCFL from the top, which characterizes temperature layers around the CCFL surface. The highest temperature on the CCFL surface is 63.3°C, but the lowest temperature 29.6°C temperature is at the lower corner of the backlight module.

Additionally, the computed density distribution in the module is characterized in Fig. 9 that characterizing lower air density in the higher portion of the module.
5.3 Flow Pattern in Backlight Module

Figure 10 shows the velocity distribution in the direct-type of backlight module, Fig. 10(a), (b), (c), (d), (e) and (f), are 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10 and 11 and 12 CCFL, respectively. The gap between CCFL in direct-type backlight module and the left/right is 14:1 in size ratio. The temperature on the right side is higher than the left side temperature, therefore, a reverse flowing exists.
5.4 Cell Flow in the Direct-Type Backlight Module

Figure 11 is the steady state velocity distribution in the 2nd and 3rd CCFL. There is a cell flow in the upper left CCFL. It is also called reverse fluid. This study is laminar flow for the Reynold number is very small. The flow passed by the CCFL is not separated. Figure 12 is the expression diagram of the whole air flow velocity by CFD. The red line is velocity direction and the blue line is cell flow. There are 11 cell flows in the direct-type backlight module.

5.5 Structure Heat-Transfer of TFT-LCD TV Panel

Figure 13 shows the temperature distribution in the TFT-LCD TV panel, compared with Fig.14(a), (b) and (c), the analysis of temperature in the upper air layer of cell assembly of TFT-LCD TV is higher than that in the lower layer. The temperature in Fig.14(a) is 3°C higher than in Fig.14(c) based the experimental data. Temperature analysis and experimental data in the cell assembly error for steady state, T9, T10 and T11 are about 7.1%, 2.9% and 5.7%, respectively.
Fig. 14: Comparison of measured and computed temperature on the TFT-LCD TV panel.

6. Conclusions
Since concluding remarks can be summarize as follows through numerical analysis and experimental validation. The thermal energy of the plume flow generated form hot cylinders is transferred from low to high position by buoyancy in natural convection. From the results, the temperature at the upper position is 7°C larger than that in lower position in the direct-type backlight module. On the TFT-LCD TV panel, the temperature difference is 3°C. In the process of heat transmitting in the plume flow generated by the CCFLs, it is found there are layer-temperature phenomenon surrounding the CCFL surfaces.

In the CFD analysis, the flow in this laminar flow does not separate due to low Reynold number. The gap between the CCFL in direct-type backlight module and left/right side is 14:1 in size ratio. The temperature on the right side is higher than that on the left side, so the flowing direction is reverse. There are 11 cell flows in the direct-type backlight module. The maximum temperature is as high as 64°C in the backlight module, and the velocity field ranges between 0~0.03 m/s in the natural convection. Reducing diameter of CCFLs in the future study is considered. Under the same electric power, it is expected to reduce temperature raising in the direct-type backlight module.

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Reference