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A Numerical Study of a Square Cell Filled with Ice with the Presence of Different Length Slit Inside the Cell

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ABSTRACT

A numerical analysis of a square cell filled with ice to determine how the existence and size of an internal incision affect the cell's behaviour. Using ANSYS/FLUENT V.16 software, the enthalpy-porosity combination was used to investigate the paper quantitatively. The material used in the study is ice. The findings of this research reveal that the time of melting for ice is lowered as the length of the break within the cell increases. The melting process takes (70) minutes to finish in a cell with a slit length of (8 cm). A cleavage length of 6 centimetres necessitates a melting time of 120 minutes. Additionally, a cell with a cleavage length of (4 cm) requires (150 min.) to finish melting.

1. Introduction

Given her central role in shaping contemporary civilization and the pervasiveness of her work in every facet of life, she has considerable sway over its trajectory. Others are known to run out in the future, while certain energy sources are known to have substantial negative effects on the environment. Consequently, scientists worldwide are researching substitutes for renewable energy sources. Long-term economic viability and no negative environmental effects are just two of the many advantages of renewable energy. Even though sources as if wind and sun have the potential to be used anywhere, their lack of constant access is the major disadvantage [1-3]. Storing thermal energy might be the solution to this problem. In the case of thermal energy storage, PCMs are the major components used [4]. Numerous studies have looked at different shapes that combine phase-changing materials as well as how shape affects thermal energy storage. Copper rods seem to be the best material for enhancing heat transfer, according to earlier study. The study showed how useful numerical forecasts are for experimental research [5]. Melting process in a rectangular PCM-filled cell is the subject of this experimental study. As the temperature increases, melting speeds up [6]. The cost of energy for both latent and sensible heat for PCM increases dramatically with a rise in intake air temperature [7,8]. An experimental and numerical analysis for the melting process of PCM was conducted in a rectangular container. The study found that melting advances faster as heat is

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applied. [9,10] Researchers ran a numerical simulation to look into thermal energy storage using a cylinder filled with PCM. Because of the extremely high temperature of the PCMs near the centre of the PCM cylinder, the first cell of cylinders in the column started to melt before the other cylinders. [11] presented a numerical simulation to look into thermal energy storage using a cylinder filled with PCM. The PCMs at the middle of the cylinder reach exceptionally high temperatures, causing the first cell of cylinders in the column to melt before the others [12]. A vertical cylindrical tube's partial PCM melting was the subject of additional research. A number of factors, including tube shell thickness, pipe diameter, thermophysical properties, and outer wall surface temperature [13]. According to the study, boosting the heater lead's wattage will hasten melting [14,15]. Experimentation on the PCM melting based on spherical cells. The results of the study suggest that increasing cell lead diameter will reduce melting [16]. The melting process of PCM in a spherical cell was analysed numerically. The investigation's findings reveals that the lower half of the sphere's effect of a natural convection is smaller than that of the top religion. A researcher [17] carried out experimentally to store latent heat for solar energy in tubes and shells utilising PCMs. The primary mechanism for heat transfer is natural convection, and melting is accelerated by the buoyant effect closer to the top [18,19]. According to the studies, the melting process may be accelerated by either raising the temperature or increasing the number of tubes. A study [20] carried an in-depth analysis of PCM melting in a tube and shell. The research reveals that heat tubes are affected in a particular manner by the process of melting. Boost the inner HTF tubes number while the melting process is being sped up. Few studies [21, 22] presented an experimental research to determine whether adding the nanoparticle would enhance heat transport. The study found that adding nanoparticles to PCM improves heat transport and reduces the time needed for melting. Few researchers [23, 24] revealed an experimental research by adding Nano fluids to PCMs to create a new phase that changes the material's capacity to store thermal energy. The results of investigation showed that adding nanofluid to PCM improved thermal conductivity and shortened the melting process's duration [25- 27].

Referring to the above studies, it can be stated that a critical evaluation of a square cell filled with ice with the presence of different length slit inside the cell, has not yet conducted. Thus, this study comes to full this gap in the open literature. Where the three cases were studied, each case represents a certain length of that crack to clarify its effect on the melting process of ice.

2. Numerical Procedures

2.1 Physical Model

The square cell that is being studied having a side length of (10 cm) is filled with ice. There is a crack in the middle of the cell that has been studied in three lengths (4, 6, and 8 cm). The cell is exposed to heat from three sides in addition to the crack, and the upper part is a cold source, as shown in Figure 1.

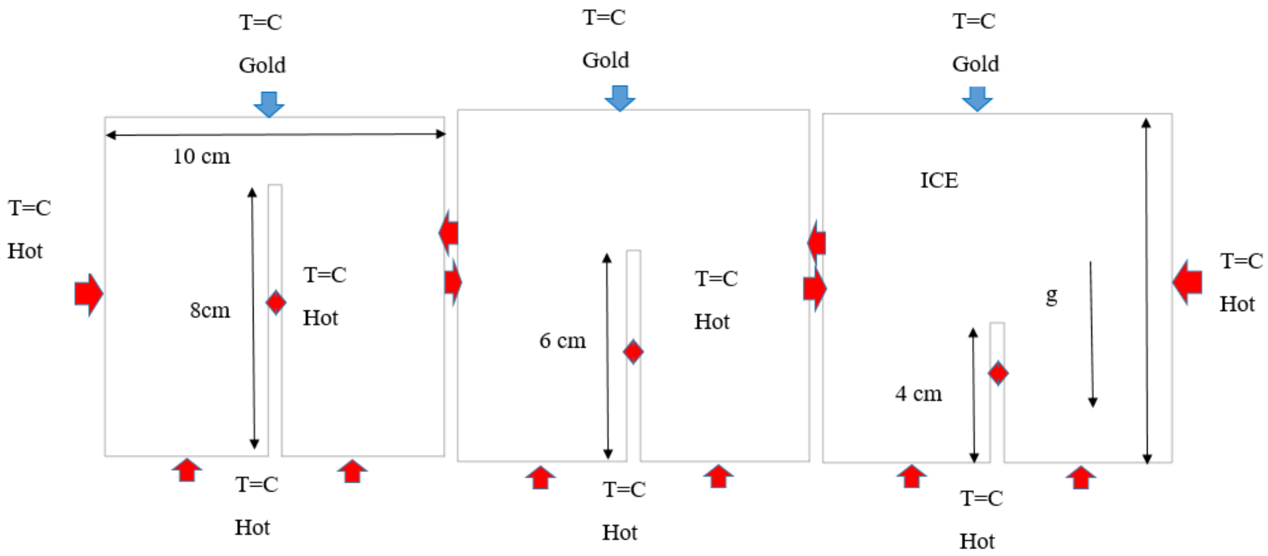

Fig. 1. Physical model configuration

2.2 Computational Procedures

The numerical analysis gives the ability to predict details of the melting processes that occur in the square cell. It was determined that the flow was two dimensional, incompressible, laminar, and unstable. In order to represent melting processes, it is often assumed that the solid and liquid phases are homogeneous, isotropic, and maintain thermal equilibrium at the interface. Method of enthalpy-porosity was adopted for the PCM's phase-change region (ice). PCM melting processes are a cardinal sin because of their nonlinearity, temporal conduct, and persistent mobility of the solid-liquid interface. Partial differential Eq. (1), (2), and (3) are used to simulate the melting processes of ice by taking into account the simultaneous continuity, momentum, and energy of the system [28]:

$$\frac{\partial \rho}{\partial t} + \nabla\,(\rho.V) = 0 \quad (1)$$

$$\frac{\partial (\rho v)}{\partial \mathrm{t}} + \nabla\,(\rho.V) = -\nabla P + \mu.\nabla^2 V + \rho.g + S \quad (2)$$

$$\frac{\partial}{\partial t}(\rho.H) + \nabla(\rho.V.H) = \nabla.(K.\nabla T) \quad (3)$$

To get the specific enthalpy H, just combine the sensible enthalpy h with the latent heat ΔH in the equation:

$$H = h + \Delta \mathrm{H} \quad (4)$$

Where,

$$h = h_{ref} + \int_{T_{ref}}^{T} C_p\, dT \quad (5)$$

$$\Delta H = \beta L_f \quad (6)$$

As the liquid fraction (β) varies from zero (for a solid) to one (for a liquid), the latent heat ability may be expressed as:

$$\beta = \begin{cases} 0 \quad \text{solidus if } T < T_s \\ 1 \quad \text{liquidus if } T > T_l \\ \frac{T-T_s}{T_l-T_s} \text{ if } T_s \leq T \leq T_l \end{cases} \tag{7}$$

The impact of phase shift on convection adds a damping component, defined by Darcy's law, to the momentum equation as the source term S. The source term in the momentum equation is given by:

$$S = \frac{C(1-\beta)^2}{\beta^3} V \tag{8}$$

Where C is a constant of the mushy zone that reflects the shape of the melting front. Typically, this fixed is a very large number (between 10^4 and 10^7). In this investigation, we fix (C) at 10^5 as a constant assumption.

2.3 Boundary Conditions

The cell that was studied is a square cell filled with ice that is exposed to a heat source from three sides (80 °C), and the upper part is exposed to a cold source (0 °C) and the crack in the middle of the cell is a heat source that enters the cell at a temperature of (80 °C)

2.4 Assumptions

The following presumptions are taken into account when determining a mathematical formula for the melting processes inside a square cell: a 2-D model of the melting is used. Initially, it is assumed that the PCM's (ice's) thermal properties are fixed in both the solid and liquid phases, the flow is unsteady, laminar, and incompressible, the viscous dissipation term is small, the influence of volume change related with the solid-liquid phase change are disregarded, and no external heat gain or loss occurs. Figure 2 shows the mesh generation for the model being studied.

2.5 Mesh Generation

There is a series of checkpoints that must be met and approved before the present numerical simulation study can be carried out. When it is tried to condense these concepts, give special attention to these two aspects:

i. One way to reduce the amount of inaccuracy in the numerical findings is to take extra care while making the grids and examining the density of the grid components.
ii. Checking whether the utilised numerical model yields reliable results.

The grids that make up the examined region are generated and constructed using a programme called Gambit. After completion, the grid structure may be seen in its final form in Figure 2. In each example, the density of the components was deduced from the value of the ratio.

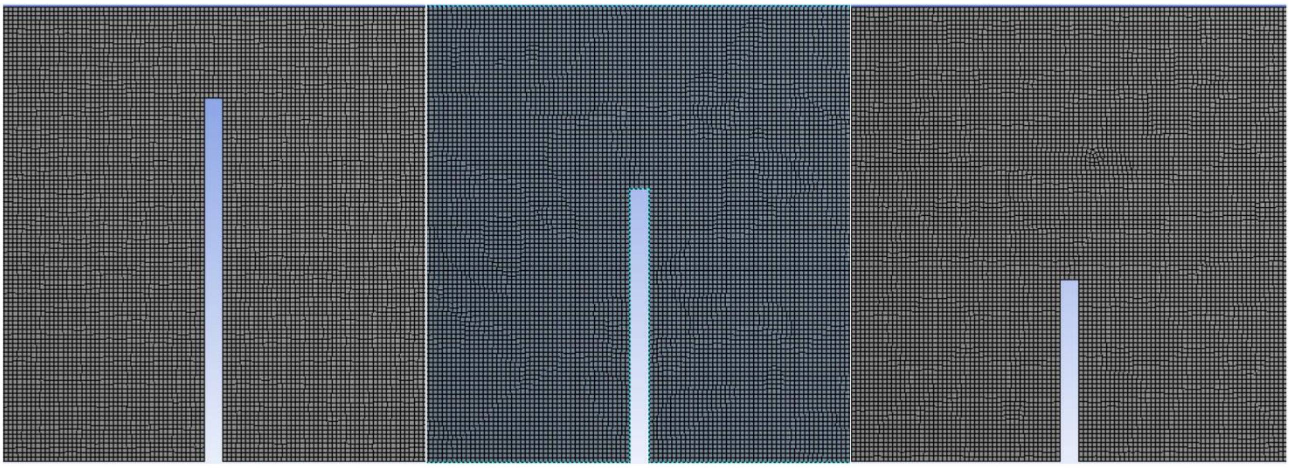

Fig. 2. Configuration of mesh

2.6 Grid independency Test

The average liquid fraction over time for the various grid sizes is presented in Table 1, which may be used to conduct the mesh independence analysis. The melting interface must be tracked at each time step, hence a well calibrated mesh across the domain is essential. Figure 3 shows how changing the mesh size during melting affects the liquid fraction. The Grid(2) mesh is used for all of the numerical simulations in this study. This mesh was chosen based on the results of the mesh independence analysis.

Table 1
Grid independency test for numerical results.

Meshing	Grid1	Grid2	Grid3
Elements number	25,416	30,772	58,662

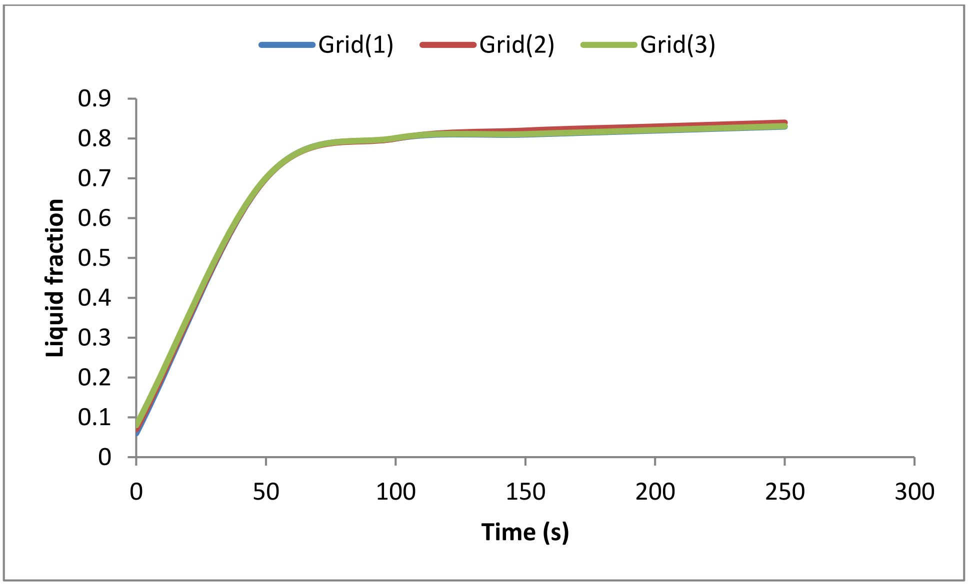

Fig. 3. Grid independency test

The liquid percentage of ice with time is resolved using the computational technique described in this study, which was created by Abderrahmane *et al.,* [29]. There is a very high degree of confidence, as the difference in Figure 4. These similarities attest to the method's accuracy.

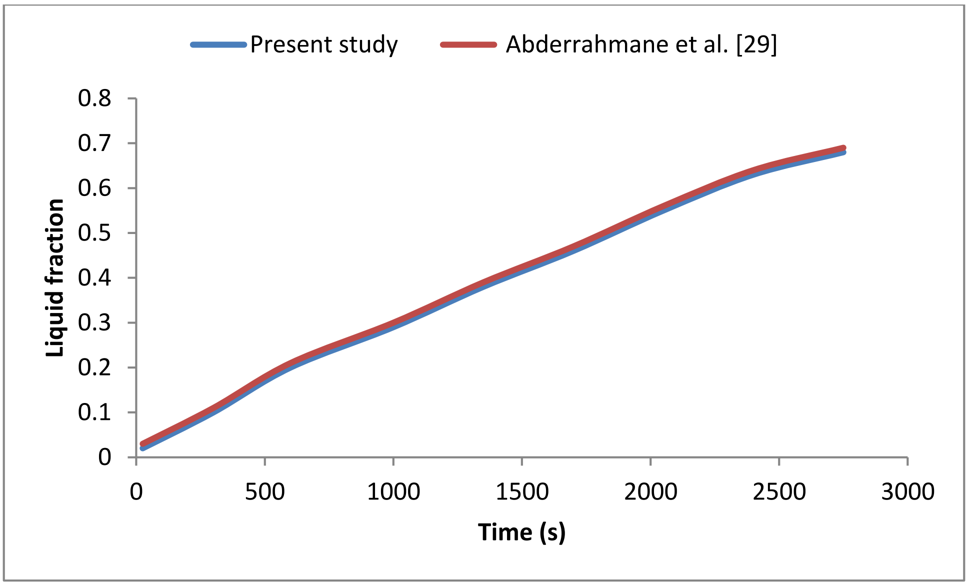

Fig. 4. Comparison with results of reference [29]

3. Results and Discussion

Three cases of the cell are studied, each case depends on a certain length of the slit to clarify its effect on the ice melting process. The slit was placed in the middle of the square cell and a heat source was threated from the slit into the cell. The importance of the study shows the effect of the presence of slits in the cells with different length on the process of melting of ice.

3.1 Case One (Slit Length of 8 cm)

In this case, the cell is studied with an incision of 8 cm in length. We note in Figure 5 that the melting process is affected by the conduction in the melting process allowance along the three sides that are the source of heat. When the ice is pushed away from the wall, it is obvious that the melting process relies on the natural load rather than the slit's influence alone. Because natural convection is the primary mode of heat transport, we find that melting progresses more slowly farther from the wall. We see the melting process progressing upwards because the higher elevations are unaffected by the melting process as cold sources. In Figure 6, we see the transfer of heat to ice. At the beginning, it can be noticed that the ice gain heat transfer directly from the wall because it depends on the conduction, and it is slower as we move away from the wall because it depends on the natural convection. In Figure 7, one can observe the movement of melting, which is initially near the wall and then moves to the ice, this verified very well with previous studies [30-32].

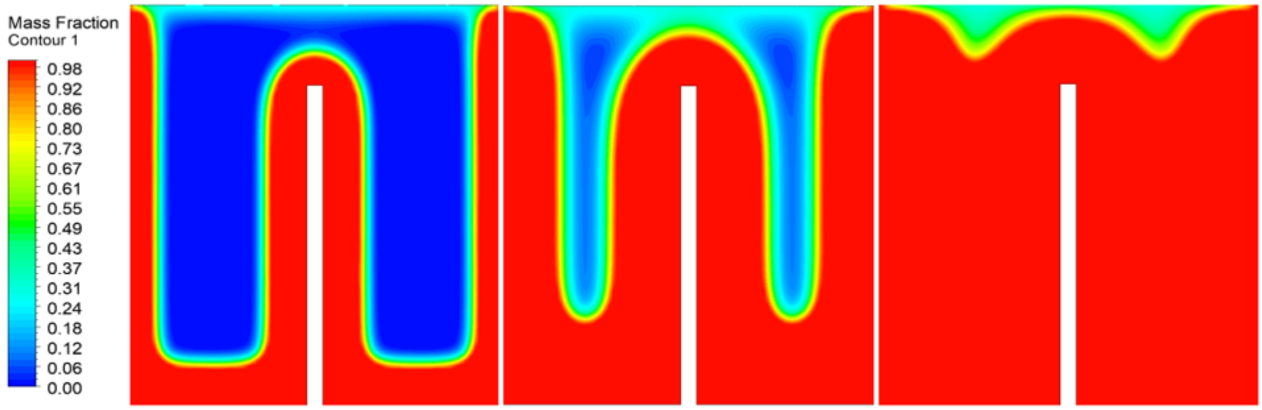

Fig. 5. Predicted evolution of the melting process with slit length of 8 cm

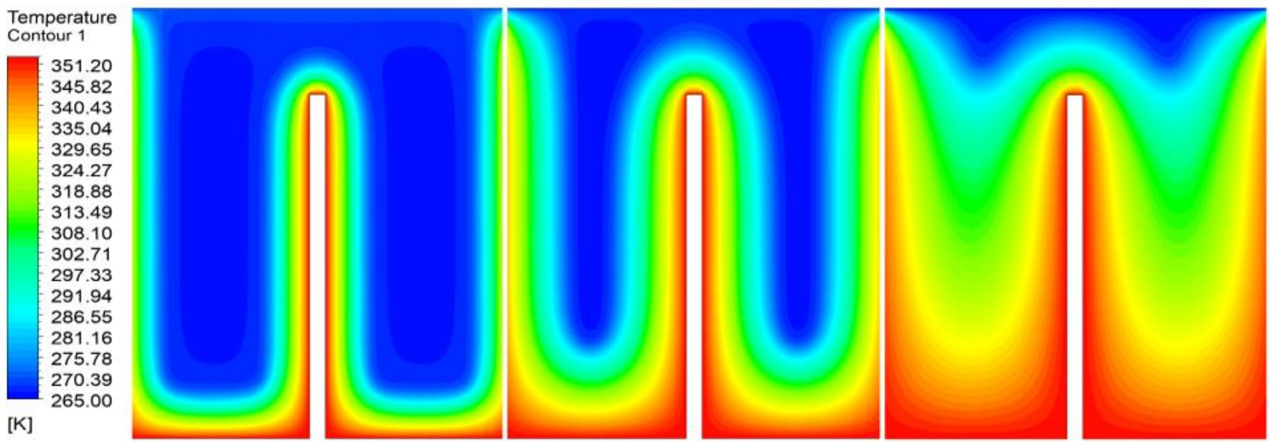

Fig. 6. Temperature distribution with slit length of 8 cm

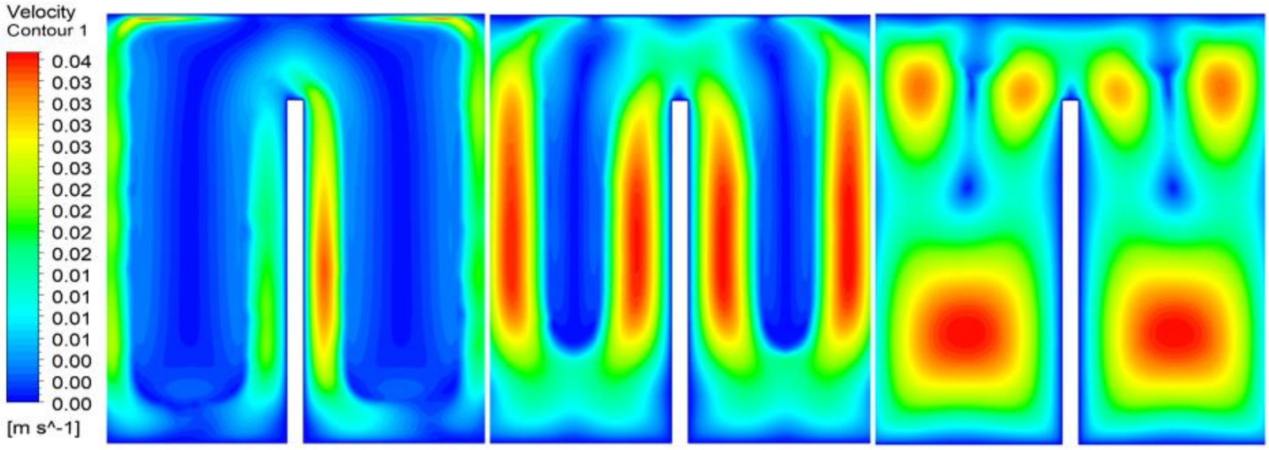

Fig. 7. Velocity distribution with slit length of 8 cm

3.2 Case Two (Slit Length of 6 Cm)

In this scenario, a 6-cm incision is made to access the cell for analysis. Conduction in the process of melting is influenced by the replacement of melting along the three sides that are regarded the source of heat, as shown in Figure 8. It is obvious anytime you move ice farther from the wall that the slit has less of an impact on the melting process than in the prior scenario. Because natural convection is the primary mode of heat transport, we find that melting progresses more slowly farther from the wall. It can be seen that the melting process moving to the top because the upper part is considered a cold source and has no effect on the melting process. Figure 9 presents the transfer of heat to ice. At the beginning, the ice get heat transfer directly from the wall because it depends on the conduction load, and it is slower as we move away from the wall because it depends on the natural convection. Figure 10 reveals the movement of melting, which is initially near the wall and then moves to the ice, this verified very well with previous studies [33, 34].

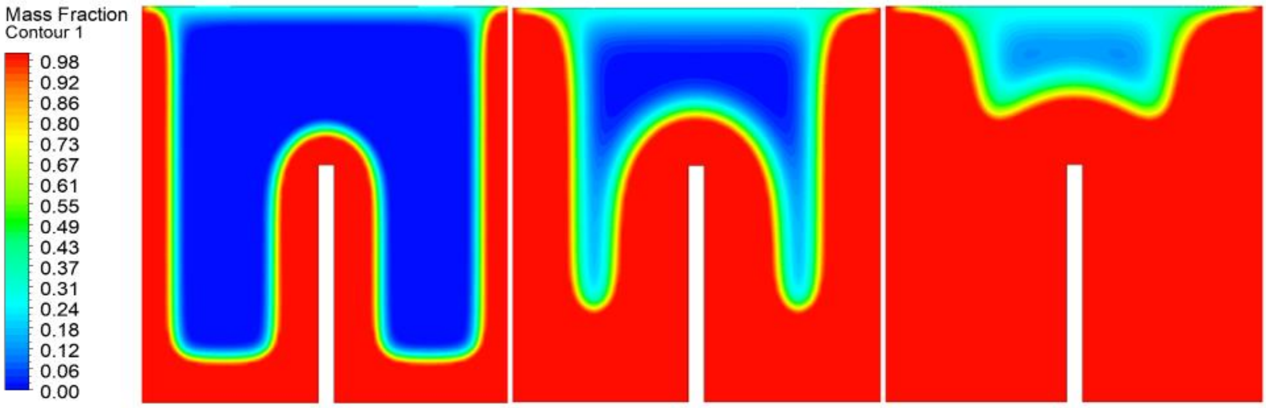

Fig. 8. Predicted melting process progression with 6 cm slit

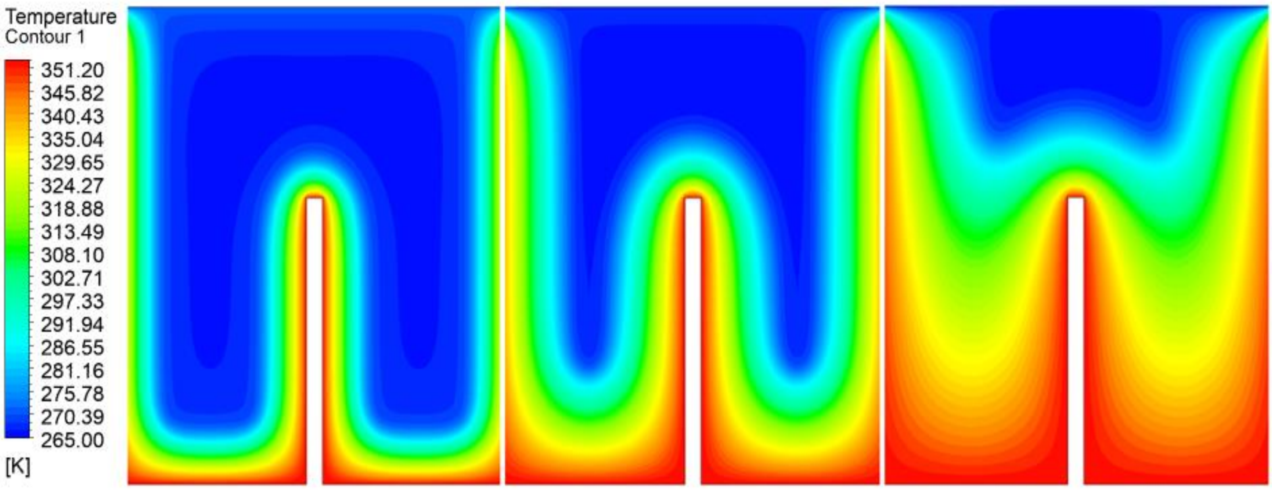

Fig. 9. Temperature distribution with slit length of 6 cm

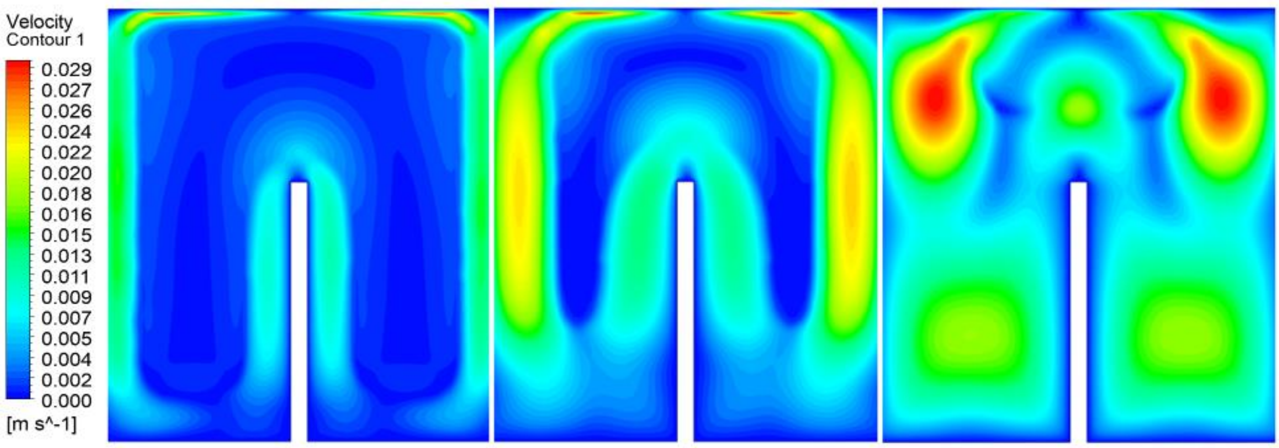

Fig. 10. Velocity distribution with slit length of 6 cm

3.3 Case Three (Slit Length of 4 Cm)

In this case, the cell is studied with an incision of 4 cm in length. Figure 11 reveals that the melting process is affected by the conduction in the substitution of the melting process along the three sides that are considered the source of heat. In addition, here the effect of cracking is less than the previous cases on the ice melting process, then the melting process depends on the natural load, which is clear whenever move the ice away from the wall. Since natural convection is the primary mode of heat transport, it stands to reason that the melting process would be slower farther from the wall. We see the melting process progressing upwards because the higher elevations are unaffected by the melting process as cold sources. Figure 12 presents the transfer of heat to ice. At the beginning, it can be noticed that the ice get heat transfer directly from the wall because it depends on the conduction, and it is slower as moving away from the wall because it depends on the natural convection. Figure 13 reveals the movement of melting, which is initially near the wall and then moves to the ice, this verified very well with previous studies [35, 36].

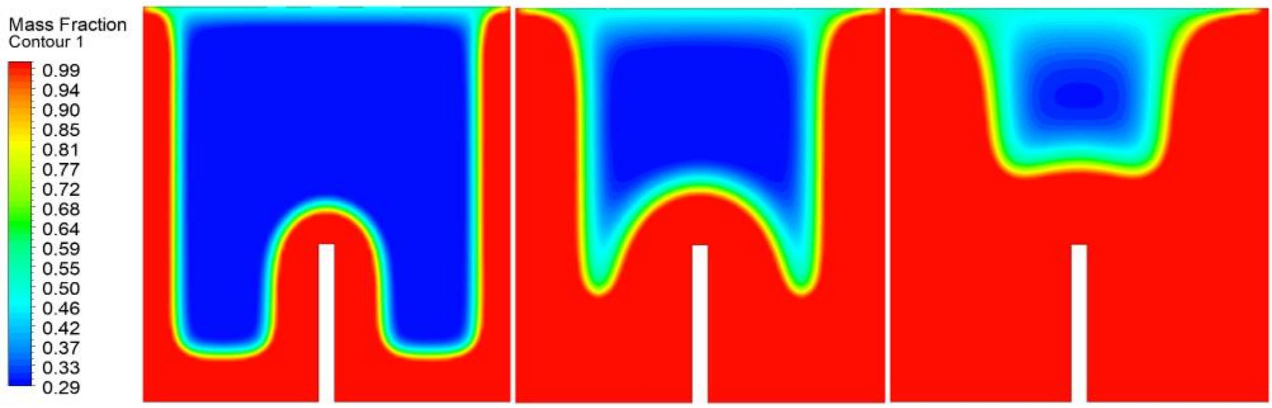

Fig. 11. Predicted melting process progression with 4 cm slit

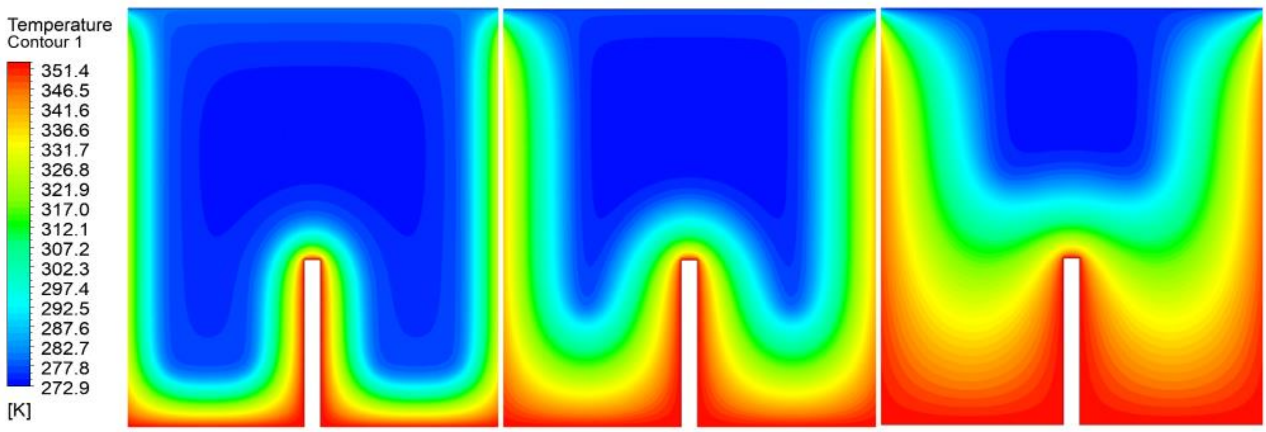

Fig. 12. Temperature distribution with slit length of 4 cm

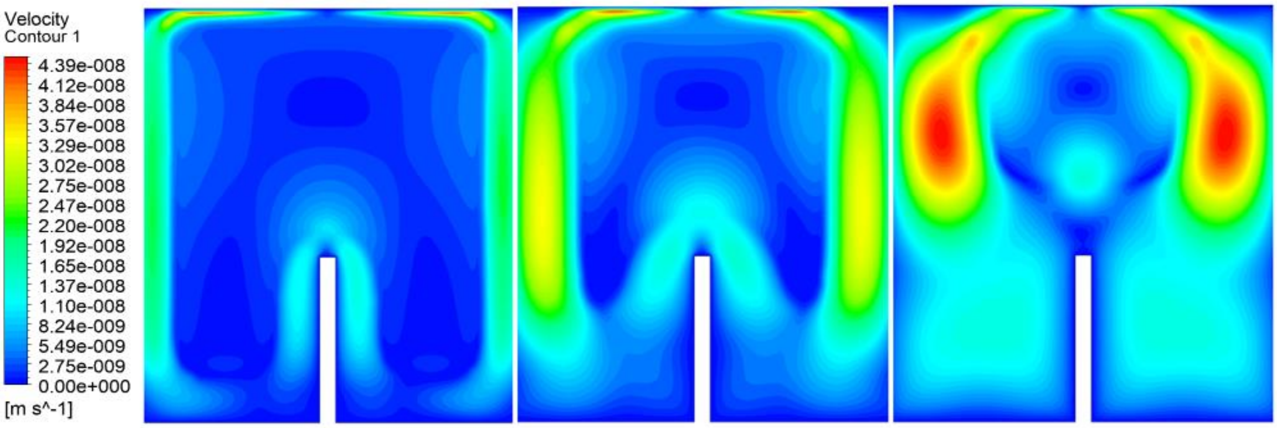

Fig. 13. Velocity distribution with slit length of 4 cm

3.4 Comparison between the Three Cases

We find that the existence of the crack has an important impact on the process of ice melting, and that the process of melting accelerates with increasing slit length. Figure 14 shows how the presence of a crack affects the melting of ice; we can see that the length of the crack has a significant impact on the melting process, and that this is because of the increased heat transfer within the space. Figure 15 shows that it takes the cell with a slit length of 8 cm 70 minutes to melt completely. It takes a cell (120 minutes) to melt at room temperature if its cleavage length is 6 centimetres. It takes a cell (150 minutes) to melt at room temperature if its cleavage length is 4 centimetres. The existence of the break within the ice greatly affects the solubility process. Figure 16 shows a temperature contrast at a location above the cell, illuminating the impact of the slit on heat transport, this verified very well with previous studies [37, 38].

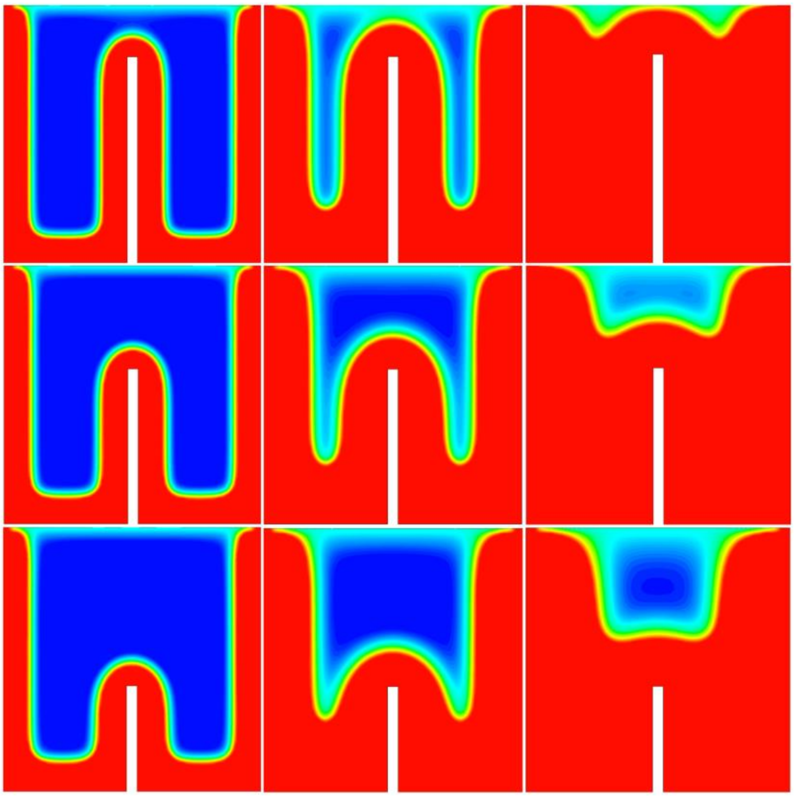

Fig. 14. The melting process in three situations

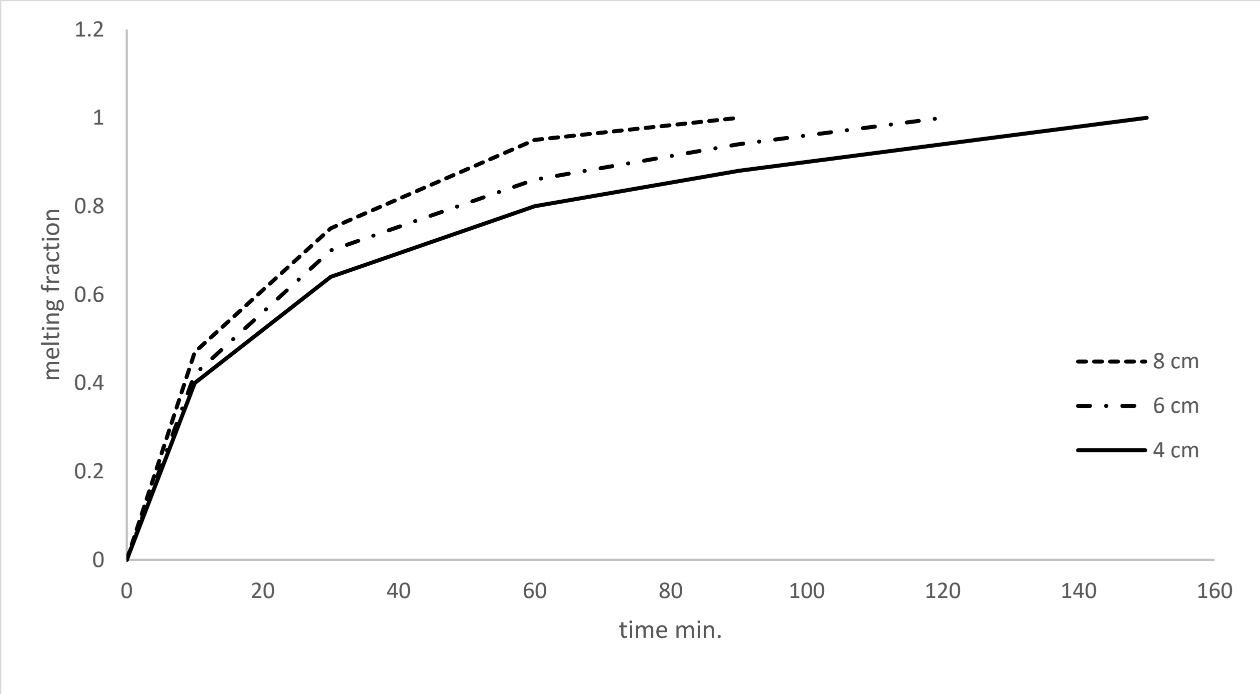

Fig. 15. Variation of melt fraction for the three cases

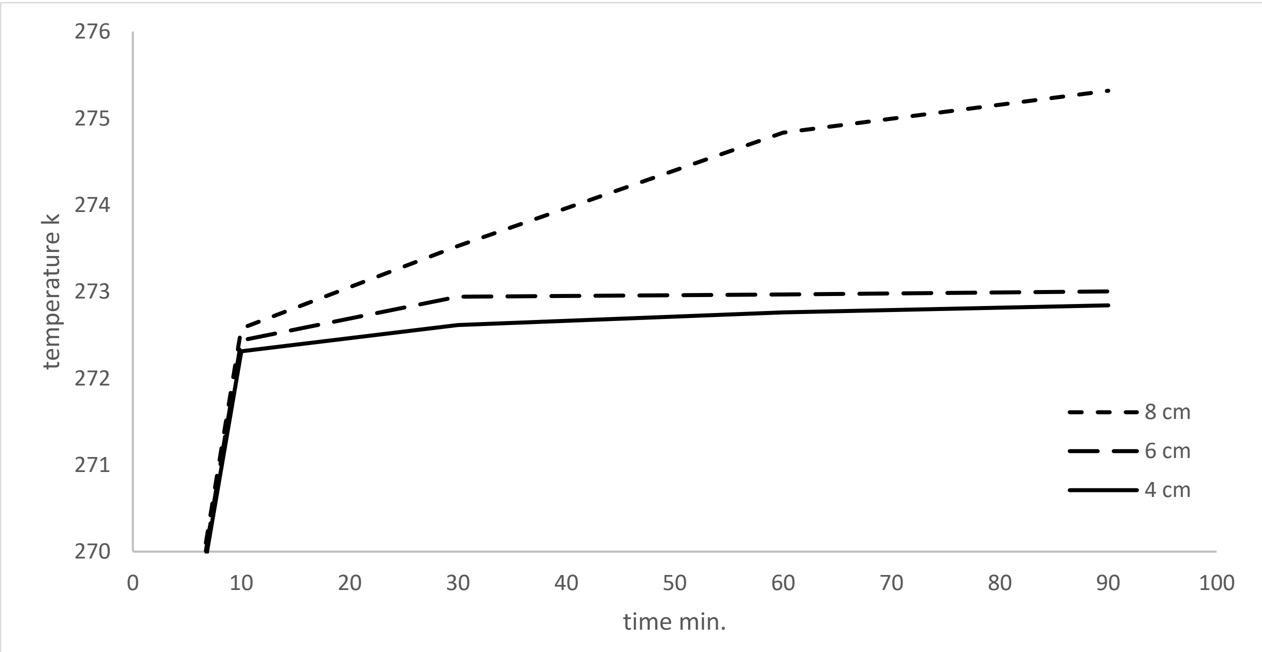

Fig. 16. Comparison of the temperature at point on the top of cell among the three cases

Figure 17 illustrates how the slit length significantly influenced the total time of melting. Under the same heat storage effect, the highest time difference was 60 minutes, and the maximum time difference induced by the slit length was as high as 40%. When there were a certain slit length, the time of melting and heat transmission were quickest when there were slit length of 8 cm. Research demonstrated that appropriately using slit in the cell may significantly enhance heat transmission during melting. The total melting time essentially reduced as the slit length increased. The neighbouring fluid flow between the slit may slow down or even stall if the slit length is blindly increased while the spacing between slit is reduced, this verified very well with previous studies [39-43].

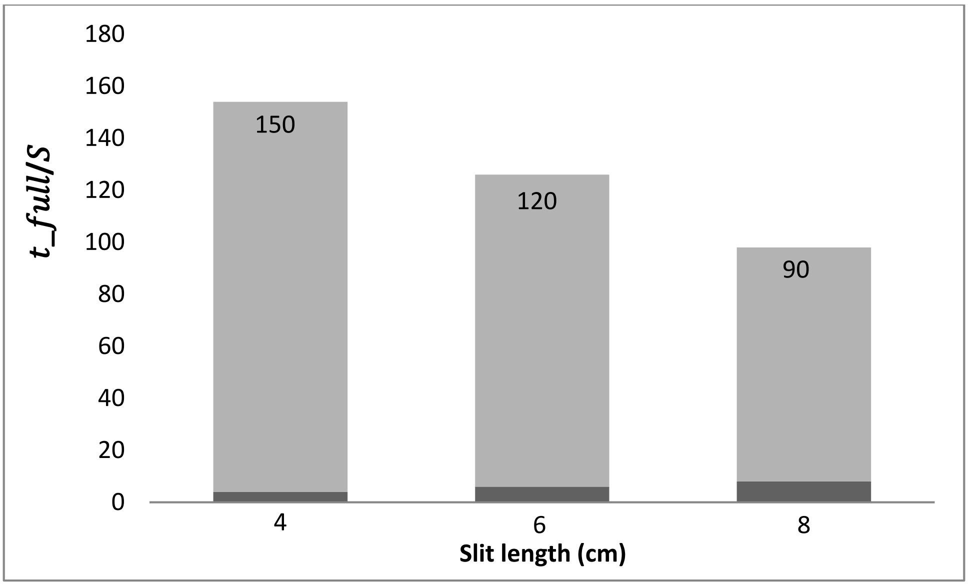

Fig. 17. Complete melting time versus slit length

4. Conclusions

To investigate how the presence and extent of an internal incision effect the cell's behaviour, a numerical analysis of an ice-filled square cell is performed. The enthalpy-porosity combination was quantitatively examined using the ANSYS/FLUENT v. 16 software. Ice was the study's primary material. The melting process is significantly affected by the crack's length, as shown by this research. The melting process takes (70) minutes to finish in a cell with a slit length of (8 cm). A cleavage length of 6 centimetres necessitates a melting time of 120 minutes. Additionally, a cell with a cleavage length of (4 cm) requires (150 min.) to finish melting.

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