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Turbulent fluid flow and heat transfer analysis of heated rectangular blocks encountered in electronics enclosures

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Abstract. Computational investigation of steady, two-dimensional heat transfer attributes for forced convective chaotic discharge in a vertical channel of cluster of heated rectangular sections is performed. The discharge is deemed to be periodic fully developed so that the issue is determined for two extending zone and explanation is developed to more number of sections. This structure reproduces the driven convective cooling of a cluster of engraved circuit panels confronted in computerize belongings. Two mathematical statements for k- Ɛ model is used for modeling for the turbulence and the finite volume methodology is used. Computations are performed for Reynolds numbers ranging from 6000-12000, Prandtl number of 0.7 and various geometric parameters characterizing the problem. As Reynolds number steps up the Nusselt Number increases. Re-circulations undermine the local Nusselt number when matched with comparing variation from a identical plate. The velocity contours, temperature distributions, variation of turbulent kinetic energy and kinetic energy dissipation rates in a vertical channel is found. With the blocks in the cluster, pressure fall is higher in resemblance to plane duct.

Nomenclature

Ar Aspect Ratio
k Kinetic energy of turbulence (J/kg)
Nu_x Nusselt number along the block
P Absolute pressure in Pa
Pr Prandtl number
ρ_s Density of solid kg/m^3
k_s Thermal conductivity of solid W/m K
Q Heat generated per unit width in W/m
Re Reynolds number
α Diffusivity of the circuit board surface in m^2/s
ε Turbulent kinetic energy dissipation rate
C_{ps} Specific heat of circuit board surface j/kg k

1 INTRODUCTION

There are several electronic equipment in practice, which contain many printed circuit boards stacked in shelves. The cooling of such printed circuit boards is done by blowing air through the stacks. The power requirement for the blowers is best, if kept at a minimum. Further, the airflow rate must be such that the surface temperature of the electronic chips is a minimum. Forced convective cooling of digital belongings proceeds to be an necessary thermal control process in operations, which consist of chip arrangement for exclusive personal computers, laptops, signal processors and workstations. Further leady application may consist of mixed circuit arrangement in marvelous data processors, housewares, projectile advancement, and rocket and arena conversation gadgets. The current issue involves the improvement of the numerical design for the chilling technique of Integrated Chips placed on a vertical circuit printed circuit boards. Kim and Anand [4] study revealed that substrate conduction could be an influential criterion in the arrangement and interpretation of chilling carriers of computerized belongings.

2 PROBLEM FORMULATION

Which The problem geometry and system of the two-dimensional vertical channel is as shown in the figure 1. The problem consists of flow through a vertical channel with discrete heat sources mounted on the vertical wall. The discrete heat sources are considered to be protruding. Both the sidewalls are assumed to be adiabatic. The fluid enters at a uniform velocity and leaves with a fully developed profile. The width of the channel is '2L'. The height of the heat source is 'H'. The width of the heat source is 'w' and the spacing between the heat sources is 's'. The air enters with a parabolic profile from the bottom and leaves the top of the plates carrying the heat dissipated by the blocks. The periodic conditions for both vertical and horizontal velocities are written as

$$u\ (x,y) = u\ (x+w+s,\ y) = u\ (x+2w+2s,y) \qquad (1)$$

$$v\ (x,\ y) = v(x+w+s,\ y) = v(x+2w+2s,y) \qquad (2)$$

The periodic condition for pressure is,

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$$p(x, y) = -\beta.x + p^1(x, y) \tag{3}$$

Where,

$$\beta. = \frac{p(x+w+s, y) - p(x, y)}{(w+s)} \tag{4}$$

$$p^1(x, y) = p^1(x+w+s, y) = p^1(x+2w+2s, y) \tag{5}$$

here p^1 is periodic component of pressure
The periodic component for Temperature

$$T(x, y) = \sigma.\, x + T^1(x,y)$$

$$\text{where, } \sigma = \frac{T(x+w+s, y) - T(x, y)}{w+s} \tag{6}$$

and $T^1(x, y) = T^1(x+w+s, y) = T^1(x+2w+2s, y)$ (7)
here T^1 is periodic component of temperature.
After the periodic conditions are applied the physical domain for the present problem is as shown in figure 1.

$$\frac{\partial u}{\partial x} = 0,\ \frac{\partial v}{\partial y} = 0,\ \frac{\partial T}{\partial x} = 0, \frac{\partial k}{\partial x} = 0, \frac{\partial \varepsilon}{\partial x} = 0$$

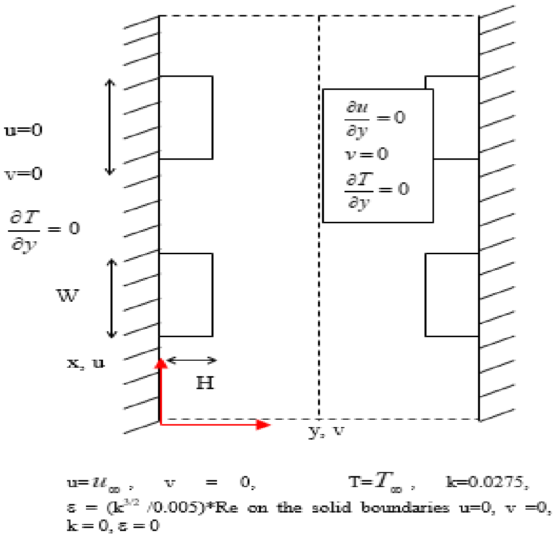

Fig: 1 Physical Domain of PCB

3 Mathematical Formulation

Due to the numerical strategy the governing equations along with the initial and boundary conditions are written in pseudo transient form. The pseudo-transient form of the two-dimensional equation for the heat conduction in the solid block with uniform heat generation is:

$$\frac{\partial T}{\partial t} = .\frac{Ks}{\rho_s.C\rho_s}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{Q}{K_s}$$

The equations governing the velocity and temperature fields within the fluid domain have been thoroughly reviewed. For a turbulent, two-dimensional forced convection flow of Newtonian viscous fluid, the equations for the primitive variables are written as,

$$\text{Continuity: } \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{8}$$

x-momentum:

$$u\frac{\partial u}{\partial x} + v.\frac{\partial u}{\partial y} = \frac{-1}{\rho_f}\frac{\partial p}{\partial x} + \upsilon_f\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{9}$$

y-momentum:

$$u.\frac{\partial v}{\partial x} + v.\frac{\partial v}{\partial y} = -\frac{1}{\rho_f}\frac{\partial p}{\partial y} + \upsilon_f\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{10}$$

Turbulent Kinetic energy: (11)

$$u\frac{\partial k}{\partial x} + v\frac{\partial k}{\partial y} = \frac{\partial}{\partial x}\left(\frac{1+\frac{\upsilon_t}{\sigma_k}}{\mathrm{Re}}\frac{\partial k}{\partial x}\right)$$

$$+\frac{\partial}{\partial y}\left(\frac{1+\frac{\upsilon_t}{\sigma_k}}{\mathrm{Re}}\frac{\partial k}{\partial y}\right) + \frac{1}{\mathrm{Re}}\left\{\upsilon_t.\left(2\{(\frac{\partial u}{\partial x})^2 + (\frac{\partial v}{\partial y})^2\} + (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2\right) - \varepsilon - 2\left\{(\frac{\partial k^{\frac{1}{2}}}{\partial x})^2 + (\frac{\partial k^{\frac{1}{2}}}{\partial y})^2\right\}\right\}$$

Turbulent dissipation rate: (12)

$$u\frac{\partial \varepsilon}{\partial x} + v\frac{\partial \varepsilon}{\partial x} = \frac{\partial}{\partial x}\left(\frac{1+\frac{\upsilon_t}{\sigma_\varepsilon}}{\mathrm{Re}}\frac{\partial \varepsilon}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1+\frac{\upsilon_t}{\sigma_\varepsilon}}{\mathrm{Re}}\frac{\partial \varepsilon}{\partial y}\right)$$

$$+\frac{1}{\mathrm{Re}}\left\{\begin{array}{l} c_{\varepsilon 1}\upsilon_t\frac{\varepsilon}{k}\left[2\left(\left\{\frac{\partial u}{\partial x}\right\}^2 + \left\{\frac{\partial v}{\partial y}\right\}^2\right) + (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2\right] - c_{\varepsilon 2}f_2\frac{\varepsilon^2}{k} \\ + 2\upsilon_t\left[\left(\frac{\partial^2 u}{\partial x^2}\right)^2 + \left(\frac{\partial^2 u}{\partial y^2}\right)^2 + \left(\frac{\partial^2 v}{\partial x^2}\right)^2 + \left(\frac{\partial^2 v}{\partial y^2}\right)^2\right] \end{array}\right\}$$

4 Strategy of numerical solution

The equations are the numerical depiction of the paired heat transmission involving at constant time conduction in the solid and convection in the fluid. Hence, the solution of these fluid flow and heat equations is to be attained simultaneously. It is simple to see that the outcome of these mathematical statements is not laid-back by systematic means and has to be obtained numerically. Although it is implicated in consistent occurrence, the mathematical statements get remain produced in pseudo-transient form due to the numerical action pursued in the present investigation. The mathematical statements are discredited using control volume concept by SIMPLE algorithm by iterative strategy of arrangement of linear algebraic equations, which can prevail definitely determined by adopting FLUENT software; the consistent occurrence solution of the deciding equations can be retrieved.

Solution methodology

The result to the current issue has been obtained by running FLUENT software. FLUENT is the world driving CFD code for a broad scope of discharge modeling practices. With its long-lasting prominence of being foolproof, FLUENT makes it accessible for new users to reach up to productive pace.
Fluent is an advanced computer program for representing fluid flow and heat transfer in problematic geometries. All tasks involved to compute a solution and exhibit the outcomes are applicable through a reciprocal, menu-driven interface. Rapid geometry modeling and immense quality meshing is vital to rewarding use of CFD. GAMBIT equips the both.

5 Results and Discussions

The solution of the governing equations has been obtained by using the FLUENT software package. The channel with two discrete blocks on the walls, along the flow direction is considered for solving the problem.

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Computations are performed for Reynolds number ranging from 6000-12000. In the present analysis, the effect of Reynolds number and spacing between the blocks on the pressure drop and local Nusselt number are analyzed. The turbulent kinetic energy and dissipation rate also analyzed with the spacing between the blocks. The variation of average Nusselt number on the block surface is analyzed.The values taken for the present problem, while solving with FLUENT package are shown in Table 1.

Table 1: Data used for FLUENT simulation

Thermal conductivity of air (K_F)	0.025 w/ mK
Thermal conductivity of chip (K_S)	100 w/mK
Thermal conductivity of Channel wall (K_W)	0.25 w/mK
Heat generation per chip (Q''')	106 w/m^3
Density of air (ρ)	1.225 kg/m^3
Absolute of viscosity of air (μ)	1.7894 × 10-5 Ns/m^2
Prandtl number (P_r)	0.7
Inlet Temperature of Fluid (T_∞)	300 K

The dimensions taken for the problem are

Length of the Channel (l) = 250 mm
Width of the Channel (2L) = 50 mm
Width of the Chip (W) = 20 mm
Height of the Chip (H) = 7.5 mm

5.1 Streamlines and Isotherms

The streamlines are obtained for Re = 6000, Pr = 0.7, S = 0.03. Fig.2, shows the flow pattern in the present analysis. The streamlines are alter the shape in the vertical geometry due to the presence of the electronic chip blocks.

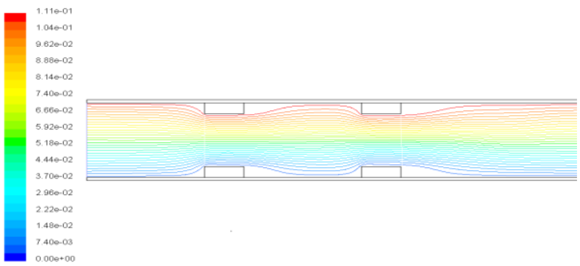

Fig.2. Streamlines along the channel for Re = 6000, Pr = 0.7, S = 0.06

The isotherms for the fluid region are obtained for Re = 6000, Pr = 0.7, S = 0.06 in Fig.3 and it is observed that the isotherms formed very close in the second block compared with the first block because the surface temperature at the second block is high.

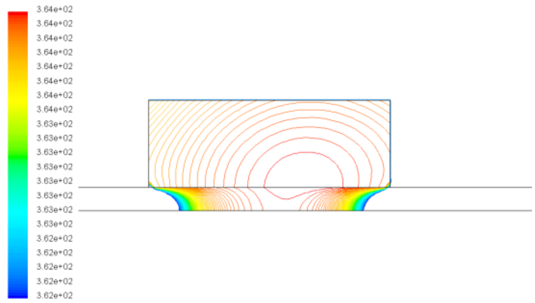

Fig 3. Isotherms in the second block for Re = 6000

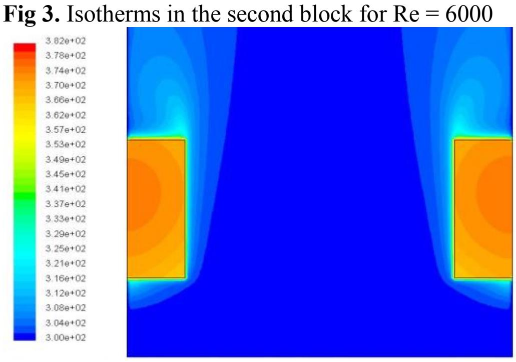

Fig. 4. Contours of temperature in the solid and fluid region near bottom two blocks for Re = 6000, Pr = 0.7, S = 0.03

The temperature of the bottom surface is less than the temperature on the top surface of the block. TheContours of temperature in the solid and fluid region near bottom and top two blocks for Re = 6000, Pr = 0.7, S = 0.03 is shown in Fig.4 respectively. The variation of the temperature with the position along the block surface is as shown in Fig.5. Due to discrete heating condition, the temperature over heat source increases with increase in distance along the channel. As Reynolds number increases the temperature in solid domain decreases, because as increasing Re, the velocity increases and more air is in contactwith the surface. So more heat transfer takes place in the flow direction.

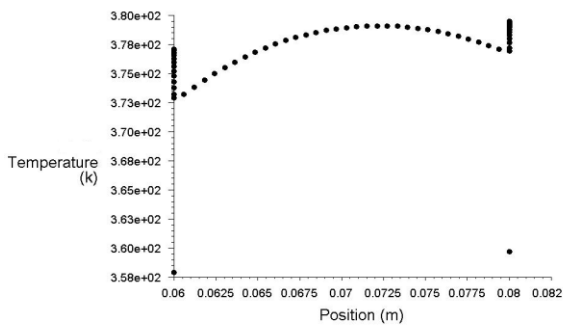

Fig 5. Variation of temperature along the top surface

5.2 Velocity vectors and constant velocity curves

The velocity trajectories sh ownin Fig.6 for Re=6000, Pr=0.7,S=0.03 reveals a certain re circulation strengthened ahead and later the block. The re circulation after the second chip is huge bigger, but further importantly, a compartment of recirculation flow establish on the top face of the section. This form of nature has observed both experimentally and numerically in the starting performance by Wietrzak and Poulikakos [2], modeling of discharges contains disengagement. The length of the re circulation region broadens as Reynolds number raises because thrust in the fluid is elevated.

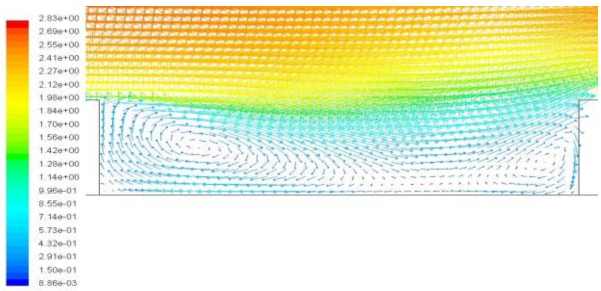

Fig 6. Recirculation between the Chips along the wall for Re = 6000, Pr = 0.7, S = 0.03

Constant U and V-velocity curves drawn for Re = 6000, S=0.03 and Pr =0.7 for two blocks in flow direction. The U and V-velocity curves is shown in Fig.7 and Fig.8. It is observed that the maximum velocity of fluid occurs over the blocks.

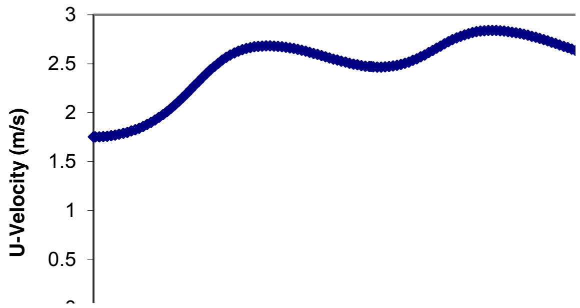

Fig 7. U-Velocity variation with the position along the channel for Re=6000 at Y = 20th grid line

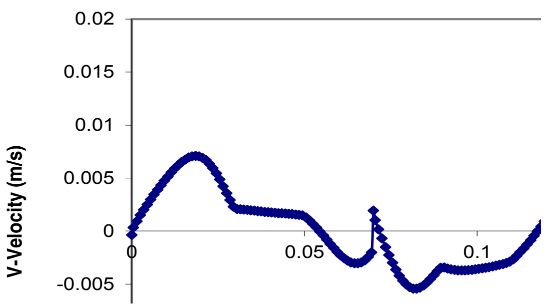

Fig 8. U-Velocity variation with the position along the channel for Re=6000 at Y = 20th grid line

5.3 Local Nusselt number

The provincial Nusselt number sharing is as shown in Fig.9, for Re = 6000, Pr = 0.7, S = 0.03. The Nusselt number deviation on the right face of the section is notably substantial i.e. the top face. It is studied that the fluid returns around the edge position (upper most), the Nusselt number stands maximal because, in the presence of a secondary boundary layer beginning at the prominent edge of top face. In this sector the ultimate value of Nusselt number shows due to re circulation along the top face and experiences violent indication on the cooling of the electronic components. In the absence of re circulation, the Nusselt number is declines monotonically along the top face, as expressed by Kim and Anand [4] for chaotic flow with protruding blocks. Studies reveal the maximum value of Nusselt number occurs at the leading edge of the corner of the top surface. Average Nusselt deviations with Reynolds number is also shown in the Fig.10.As Reynolds number widens average number also increases because temperature difference drops along the flow.

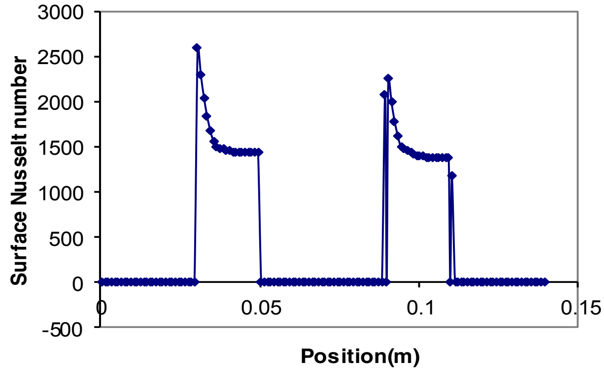

Fig 9. Variation of Local Nusselt number on the surface of the blocks in the Channel for Re = 6000, Pr = 0.7, S = 0.03

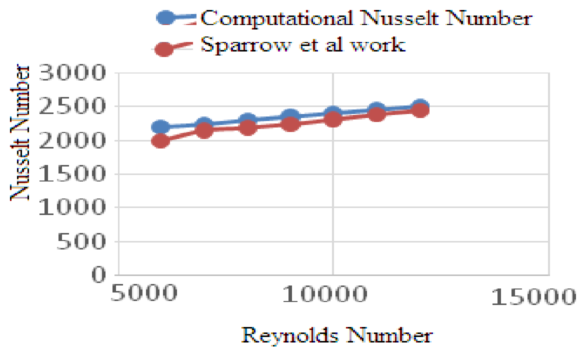

Fig.10. Average Nusselt number Variation with Reynolds number

Turbulent Kinetic Energy (k), and Dissipation rate (ε): In this investigationε, the k- study is adopted to anticipate the consequences of chaotic discharge on the heat transmission attributes of rectangular sections. Along the channel discharge, Unstable kinetic energy and dissipation rate are shown in the Figs.11 and 12 at Re = 6000.

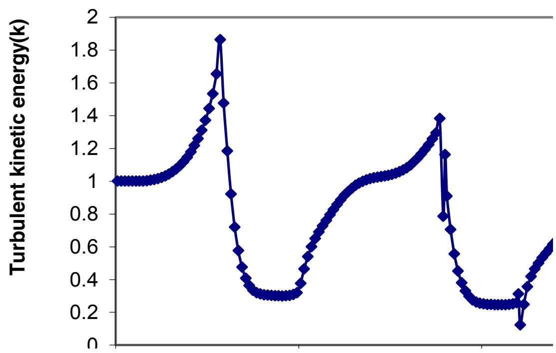

Fig 11. Turbulent Kinetic Energy variation in the Channel Re=6000

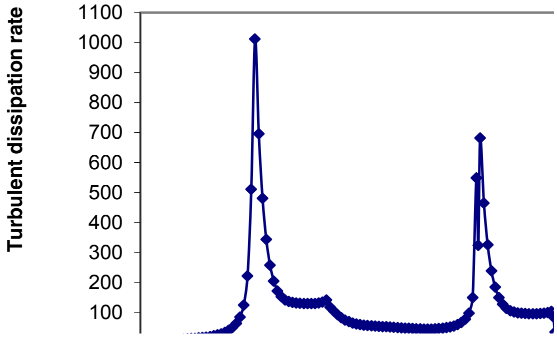

Fig 11. Turbulent dissipation variation in the Channel Re=60005.

4 Pressure drop

The deviation of pressure decline in the first and second blocks for different values of Reynolds number as shown in Fig.13, for Re = 6000s, P r = 0.7, S = 0.06. It is noted that for the first block the pressure drop rises with Reynolds number and for the second block, the pressure drop is around a constant.

The calculation of pressure drop is necessary for the prediction of the power requirements for blowing the coolant through the circuit boards. It is seen that the pressure drop is monotonic decrease with increasing Reynolds number. With the blocks in the array pressure loss is more comparison to plane channel. Below figure displays that the incremental pressure drop is due to the presence of blocks .The predicted variation is in agreement with the pioneering experimental work by Sparrow, Nithammer and Chaboki [1].

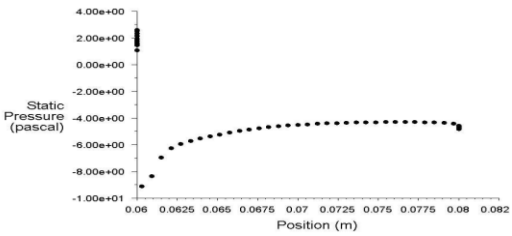

Fig 13. Variation of Pressure drop along the first block for Re = 6000, S = 0.06, Pr = 0.7

6 Conclusions

The pursuing conclusions are established from the computational examination,

1. The existence of the section instantly influences the rise in the chaotic kinetic energy near the top face of the section, which challenges a dominant position in resolving the discharge attributes.
2. The temperature of the heat sources will decline very reasonably as the Reynolds number increases. This is profoundly necessary in the cooling of electronic apparatus, heat transfer to the flow raises as the velocity increases. The bottom heat cause is comparatively cooler than the top heat causes.
3. The existence of re circulations on top, before and after the block. This recirculation is important for a peak in the local Nusselt number along the top of the chip. In the absence of this recirculation the Nusselt number reduces monotonically along the top of the chip.
4. The Nusselt number reinforces with an raise in Reynolds number. At a given Reynolds number the local Nusselt number over the top of the heat cause is the greatest for the primary source and weakens in succession for the downstream causes due to the reduction of temperature difference between the fluid and the heat cause.
5. With the sections in the cluster, the pressure fall is more in matched to plane channel, the incremental pressure decline due to presence of chips.

Acknowledgments

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