Simulation and Analysis of Microneedle for Drug Delivery based on Structural and Fluid Flow Mechanics

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***Abstract* – MEMS (Micro Electro Mechanical System) design systems are used for the development of microneedles, which are used for drug delivery. The drug delivery through micronnedle is painless which is not in case of transdermal needles. In this paper the simulation and analysis of microneedle is presented. The typical structure of a microneedle is simulated for studies of the structural behavior of microneedle and the fluid mechanics of the drug delivery. The studies show that the microneedle with silicon material can withstand the physical conditions also drugs of various viscosities with various velocities can be delivered successfully.**

Keywords – MEMS, micro needle, transdermal delivery, transdermal needle,

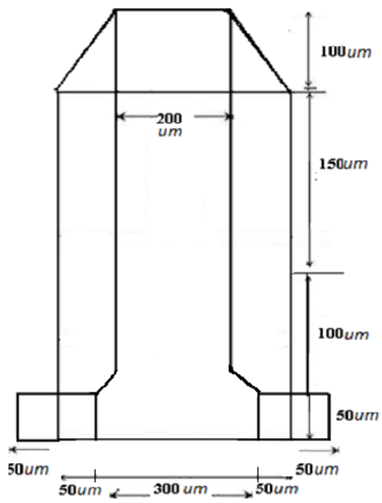
I. INTRODUCTION

MEMS (Micro Electro Mechanical System) devices are rapidly growing area of interest for a broad spectrum of applications. MEMS technology is progressively being developed for biomedical applications. One application of interest to the biomedical industry is the development of microneedles. The major drawbacks of the conventional needles are pain, risk of infection and the need of trained staff for the injection process. Also, conventional needles are not capable of sampling microscopic volume of fluids, which is often necessary in the world of lab-on-a-chip. The lab-on-chip is the promising new technology that is expected to revolutionize medical diagnostic processes. Using MEMS technology silicon based micro needles are useful for the purpose of insertion of microvolumes of various drugs with minimal invasion of tissue, and thus causing less pain [1, 2].

II. HUMAN SKIN PHYSIOLOGY

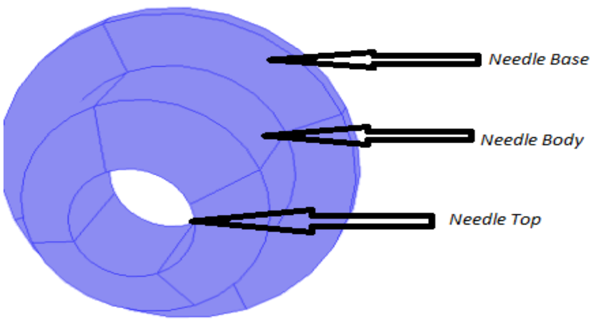
The outermost layer of human skin (10-15Microns) called stratum corneum which is primarily made of dead tissues. The next layer called epidermis (up to 50-100 micron), contains living cells and few nerves, but is devoid of blood vessels. Below the epidermis lies the third layer dermis (300-3000 micron) which contains both nerves and blood vessels [3].

III. MICRONEEDLE DESIGN



a) Cross section of Micro needle Design

Silicon microneedle is proposed for insertion of fluid into the dermis layer. The proposed design is shown in fig.a and fig. b. also This microneedle is a cylinder having length 400 µm with internal diameter 200µm and outer diameter 400 µm. The cylindrical shape of the microneedle body would provide mechanical strength to the needle than any other shape of the needle. Thus it reduces the bending of the needle.



b) Design of Micro needle

IV. MICRONEEDLE MECHANICS

The microneedle experiences resistive forces by skin when inserted into skin. Therefore, in order to penetrate the microneedle into the skin, the applied axial force on microneedle should be greater than the skin resistive forces. An axial force acts on the microneedle tip during insertion [4].This axial force is compressive and causes buckling of the microneedle. Failure of microneedle is possible during skin insertion due to bending or buckling. The axial force can be reduced by decreasing the tip area of the microneedle. As buckling is directly related with compressive force, which acts during insertion, sharp microneedle tip reduces buckling. So insertion of microneedle into the skin becomes easy. Hence, the design of microneedle is important for proper delivery without any failure.

V. SIMULATION OF MICRONEEDLE FOR STRUCTURAL MECHANICS

For simulation and analysis Comsol-Multiphysics 4.2a, a software tool is used. To show the effect of this resistive force on the structure of the microneedle, structural analysis was performed using solid mechanics. The maximum stress occurs inside the lumen section of the microneedle, which is well below the yield stress limit with negligible deflection. The result shows that the microneedle design is strong enough to penetrate into the human skin without failure.

The material for the needle was chosen to be silicon (stress of silicon =7 GPa, Young's modulus E = 160 GPa, Poisson's ratio = 0.22). The silicon is an appropriate material for micromachining and MEMS.

The base plane of the needle was considered to be fixed.

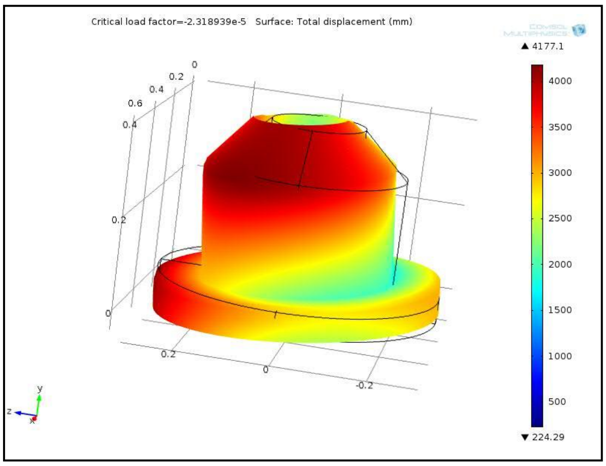
The resistive force offered by the skin before the skin is punctured is given by

$$F_{Skin} = P_{Piercing}\, A \qquad (1)$$

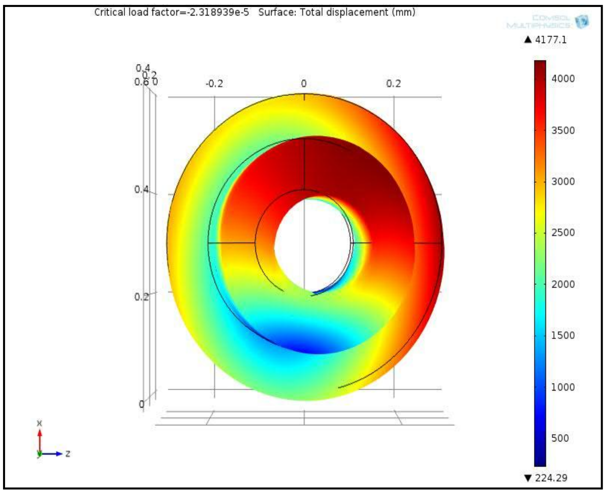
Where, Piercing P is pressure required to pierce the epidermis layer of skin, which is 3.18×10^{6} Pa. [1, 4], A is the cross-sectional area of the needle

The analysis shows that the microneedle can withstand more than 3.18 Mpa. Since the maximum buckling force was substantially larger than the skin resistive force in the microneedle and it should be able to pierce the skin without breaking.

When stress applied is 3.18 Mpa displacement of needle is shown in fig c and d.



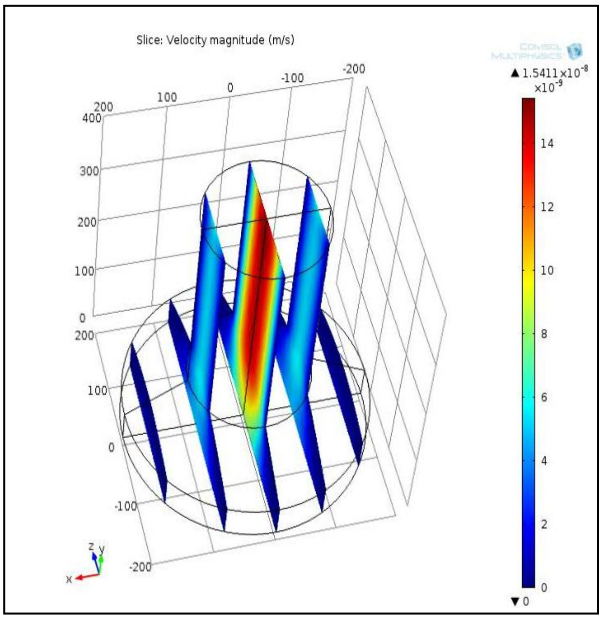
C) Stress Analysis (apply 3.18 Mpa)



d) Stress Analysis (applies 3.18 Mpa) Top view

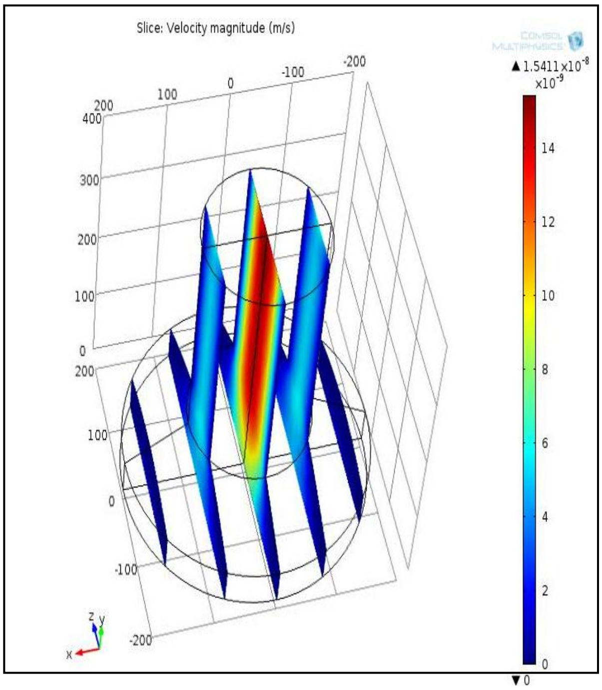
VI. SIMULATION OF MICRONEEDLE FOR FLUID FLOW MECHANICS

The fluidic analysis of the micro-needle was performed considering the Fluid Flow is a Laminar flow. The fluid (considering different types of medicine having different densities and viscosities) was modeled as incompressible, homogeneous and Newtonian. The simulations for different medicines with different densities and viscosities are performed. The simulations show that when the density or viscosity of medicine increases, the flow rate of the medicine in the micro needle decreases, which can be observed in fig. e to h.



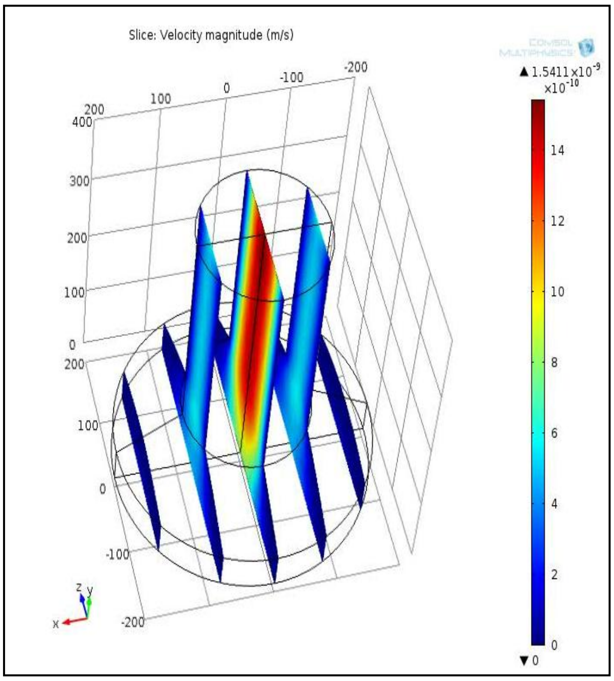
e) Medicine A (Density=1kg /m3, viscosity=1Pa.s)

Fluid Flow analysis



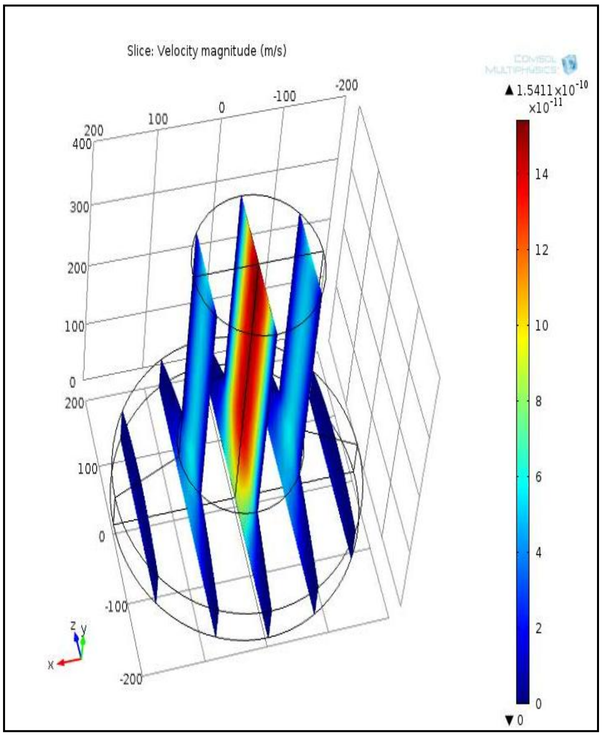
f) Medicine B (Density=10kg / m3, viscosity=10Pa.s)

Fluid Flow analysis



g) Medicine C (Density=100kg / m3, viscosity=100Pa.s)

Fluid Flow analysis



h) Medicine D (Density=1000kg /m3, viscosity=1000Pa.s)

Fluid Flow analysis

VII. CONCLUSIONS

This presented work addresses the issues related to the design and simulation of MEMS based silicon micro-needle. It presents the analysis for the micro needle that can be used for drug delivery that is capable of inserting fluid in the subcutaneous fat layer.

The maximum buckling and bending force that the micro-needle structures can withstand were simulated. Since the resistive force offered by the human skin was found to be significantly smaller than the maximum buckling and bending forces, it may be concluded that the micro needles which are made up of silicon with given dimensions are capable of penetrating the skin without breakage.

Finally it can be established from simulation results that the maximum stress and fluid flow rates were satisfactory for the chosen area of the micro-needle. The presented work provides useful information and predicted data to simulate optimized design of hollow silicon microneedle array for biomedical applications.

VIII. ACKNOWLEDGEMENT:

The authors thank NPMASS (National Program in Micro and Smart Systems) of Government of India for providing the support for MEMS design. Author also thanks management and Principal of Cummins College of Engineering, Pune for providing all the facilities for the research.

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