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CFD Analysis of Flow Behavior in Different Syringe System

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ABSTRACT

The device consists of a three way check valve connected to the syringe, compression and suction. The objective of this research is to investigate the effect of using various syringes on the fluid behavior. Theoretical analysis is carried out to study the influence of syringe diameter, valve geometry, and fluid viscosity to obtain the maximum flow rate. This work summarizes the results of the CFD analyses. In compression, the three-dimensional simulations indicate a flow turning when the syringe diameter is big. On the other hand, it is shown for small syringe diameter using low viscous fluid, the flow pattern is complex with multiple vortex structure. In suction, the syringe diameter has no effect on the pressure distribution. Future work includes improving the CFD analysis methodology. Unsteady is recommended. This study is crucial in drug delivery. Also, more studies will focus on non-Newtonian drugs.

Keywords: *three way check valve, syringe, CFD, travel force.*

1. INTRODUCTION

Fluids are persistent in a vast range of industrial processes such as pharmaceutical industry. Understating the behavior of liquid-drugs plays a critical role in a number of health-related applications and knowledge of complex fluids also has applications in emerging technologies such as novel drug delivery. The behavior of such flows under dynamic conditions in different syringes has been studied. Also mechanical and transport properties of such flow structure has been analyzed. Computational fluid dynamics (CFD) is an integral part of this research. Computational fluid dynamics is used to calculate the flow behavior in different types of syringes. The analysis of different factors such as the syringe diameter, etc.. is useful in understanding the dispensing mechanism and thus allow for performance improvement. The numerical solution can provide more information about the wall shear stress, viscosity and pressure drop which is caused by a sudden contraction. Our background and training matches our interest in curiosity driven research, which is focused on multi-disciplinary applications, but is based on basic fundamental knowledge in, fluid mechanics, thermodynamics, and CFD. We are particularly interested in the pharmaceutical applications of fluid motion of Newtonian and complex liquids.

Hospitals pre-fill disposable plastic syringes with these solutions so that they are ready for immediate use when required. Drug loss due to potential adsorption on to the plastic material of the syringes has not been studied. Atracurium is also administered by intravenous infusion using a diluted solution in either 5% dextrose injections (USP) or 0.9% sodium chloride injection USP. Drug solutions not used within 24 h are usually discarded, resulting in tremendous waste [1]. Injection force and injection time can only be reduced for a defined syringe size by increasing the needle inner diameter and to a lesser extent by decreasing the needle length. However, increasing the needle size has its limitations as it may potentially impact pain perception leading to a competitive disadvantage. Thin wall needles may be an option to increase the needle inner diameter of a cannula while maintaining the same needle outer diameter [2,3]. Pre-filled syringes (PFS) are well-established, functional container closure systems for biological products. Examples for marketed biological products available as PFS presentation include monoclonal antibody-based products, cytokines and vaccines [4]. PFS do offer some advantages over vials, e.g. (1) ease of use (and thus opportunity for self-administration or administration without further manipulations of the primary container), (2) reduction of medication errors, (3) product differentiation, (4) less overfill and (5) possibility to “combine” with an auto-injector (in case of staked-in needle PFS). The article focuses on the challenges in formulation development which apply specifically to PFS[5]. In the present work, the impact of different syringe size and the type of liquid on the flow patterns in the syringe cavity for the following three cases have been studied numerically: Syringes (3CC, 10CC and 30CC) with different diameters connected with three ways check valve have been studied.

2. PROBLEM DESCRIPTION

2.1 System geometry

Flow pattern of the fluid in the syringe can be affected by many parameters such as: the geometrical parameters, the fluid properties such as viscosity and density. In this study, the interest is focused on three sizes of the syringes and the valve. Fig. 1 shows different dimensions of the syringes.

Three different cases have been studied:

-Case 1, syringe 3 CC has been connected with three way check valve- compression and suction.

-Case 2, syringe 10 CC has been connected with three way check valve- compression and suction.

-Case 3, syringe 30 CC has been connected with three way check valve- compression and suction.

The numerical simulations can be conducted in 3D cases.

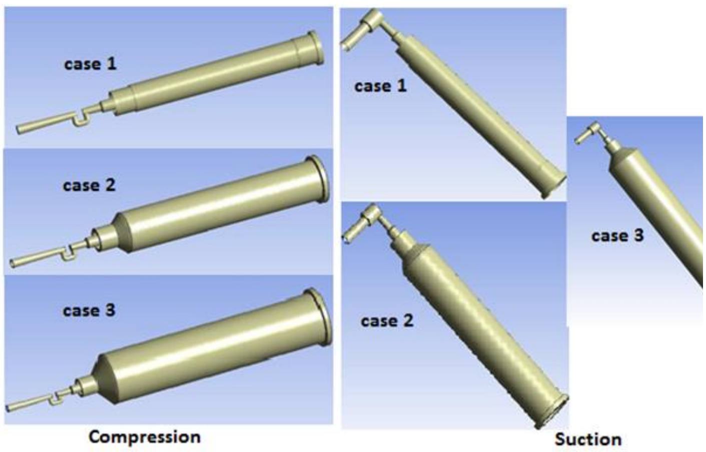

Fig. 1 shows different dimensions of the syringes connected to three way check valve.

2.2 Mathematical Equations And Boundary Conditions

For three-dimensional, incompressible and steady state Newtonian fluid, the continuity equation and the equation of motion are:

$$\nabla . V = 0 \qquad (1)$$

$$\nabla .(VV.\frac{1}{\mathrm{Re}}\nabla V) = 0 \qquad (2)$$

The continuum model leads fairly accurate predictions. For liquids, the average distance between molecules approaches the molecular diameter; therefore, liquid flows are continuum. The boundary conditions are applied on three-Dimensional syringe connected with three way check valve. The flow will be assumed to be homogeneous and no slip boundary conditions because a more viscous fluid will decrease the amount of slip for the simple reason that it is a thick fluid. For compression, the velocity is specified on the inlet. For suction, the pressure is specified on the inlet. Two working fluid with different viscosity have been used, one with low viscosity (0.001 pa.s) and the other one with high viscosity (0.8 pa.s).

2.3 Numerical solution

In the present investigation, different syringes were modeled by design-modular software. The cad package design-modular is used in different modules such as mechanical design and stress analysis. The CFD package ANSYS-FLUENT is used to solve Navier-Stokes equations. This CFD package uses the finite volume method. It enables the use of different discretization schemes and solution algorithms, together with various types of boundary conditions. As part of the same package, a preprocessor will be used to draw the geometry and generate the required grid for the solver. An unstructured grid with tetrahedral elements was used. Different meshes were used at the beginning to determine the optimum grid size as shown in Fig. 2. As a convergence criterion in the present work, the solver will be iterated the equations until it will stabilize at a constant value.

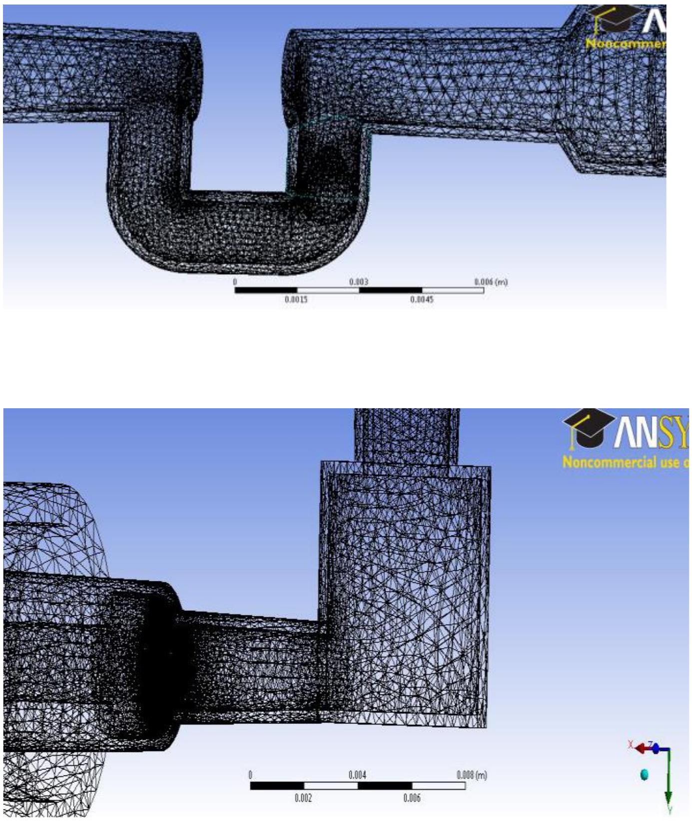

Fig. 2. Sample of meshes

3. RESULTS AND DISCUSSION

3.1 The Effect Of Syringe Diameter

Fig. 3 shows the flow pattern in different syringes with different diameter. It is observed that the average velocity along the syringe is changing with changing the syringe diameter. It is observed the creation of vortices in the 30 cc Syringe; this is due to the decrease in the viscous resistance to the flow and a subsequent with 30cc increase in the velocity. However, the average velocity decreases in the 3 cc syringes. Further, the 10cc investigated shows no changes in the velocity.This is due to the reduction of the shear stress resulting from the decrease in surface area of the syringe. It can be concluded that increasing the diameter of the syringe will increase the cavity and subsequently causes a flow turning.

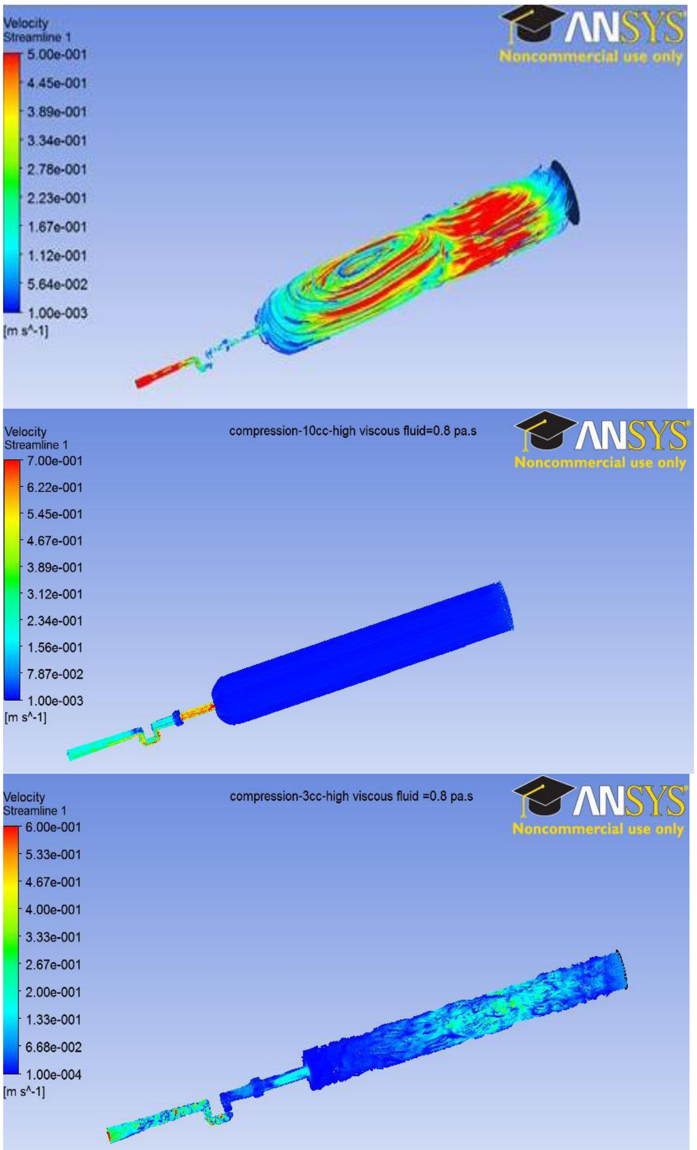

Fig. 3. Shows the flow pattern in different syringes with different diameter.

(a) 30cc, (b) 10cc, (c) 3cc

3.2 The Effect Of Fluid Viscosity On The Flow Pattern Of Compression

The present study on the syringe-valve system showed that significant flow pattern when two different viscous fluids was used. Fig. 4 shows the contour of velocity distribution in the axial direction along the syringe and valve system at low viscosity (0.001 Pas). The velocity pattern changes along the syringe. It can be noticed the existence of small vortices and this is due to the small cavity (3cc syringe) and low viscosity. However, using high viscous fluid (as shown in Figure 3-c), it can be observed a decrease in velocity along the syringe. This is due to the increase in shear stress between the high viscous fluid and the surface of the syringe.

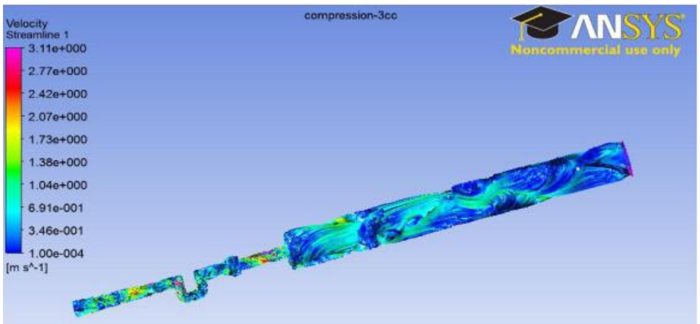

Fig. 4. The contour of velocity for low viscous fluid in 3CC syringe.

The Hagen-Poiseuille equation can be used to estimate the travel force:

$$F = \frac{8Q\mu L}{\pi R^4} A \qquad (3)$$

According to the above equation, the force depends on a number of parameters: viscosity, needle inner diameter, needle length and cross section area of the syringe. It is observed from Fig. 5 that the travel force increases with increasing the viscosity and syringe area

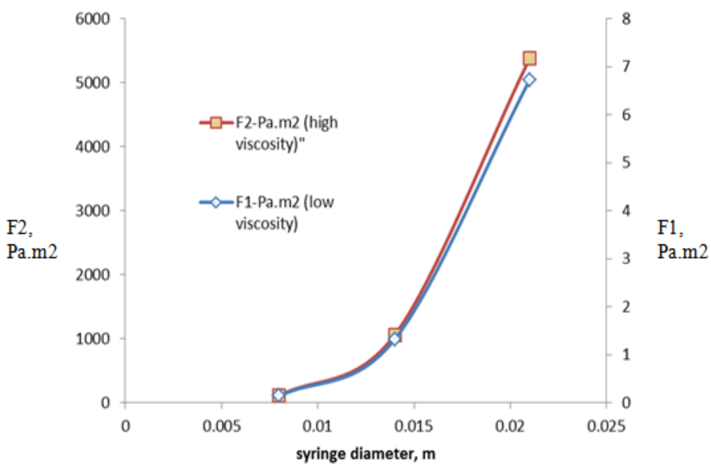

Fig. 5. Shows travel force at different viscosities as y-axis and syringe diameter

3.3 The Effect Of The Syringe Diameter On The Pressure Distribution Of The Suction

Attempting to calculate a total pressure leads to clear values since there is no effect of syringe diameter in the computational domain. However, the effect of valve geometry on the pressure distribution is significant as shown in fig. 5. On the other hand, the effect of syringe diameter is insignificant on the pressure distribution

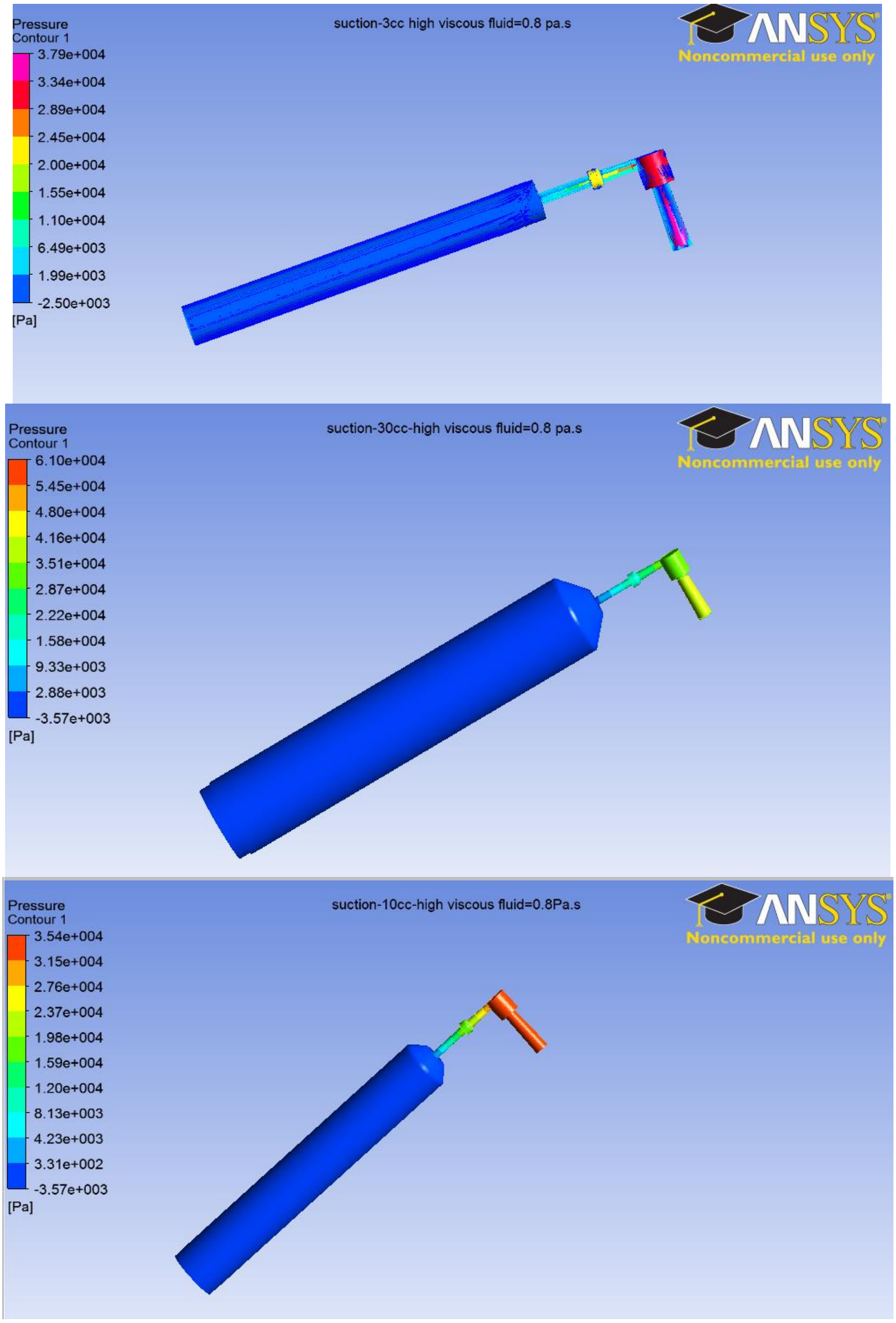

Fig. 5. Pressure contour for different syringe diameters

4. VALIDATION

The three cases of the project compare the CFD results of different syringes. The convergence of each CFD grid analysis is based on the equations residuals (Figure 6 and 7). For compression 3CC and 30CC, the Navier-Stokes equations residuals descend to a reasonable level and then exhibit an oscillatory behavior. The oscillations are the highest in 3CC syringe-compression case. The Navier-Stokes equations residuals for 10CC reach a fixed level with no oscillations. The suction with different syringes shows no oscillation.

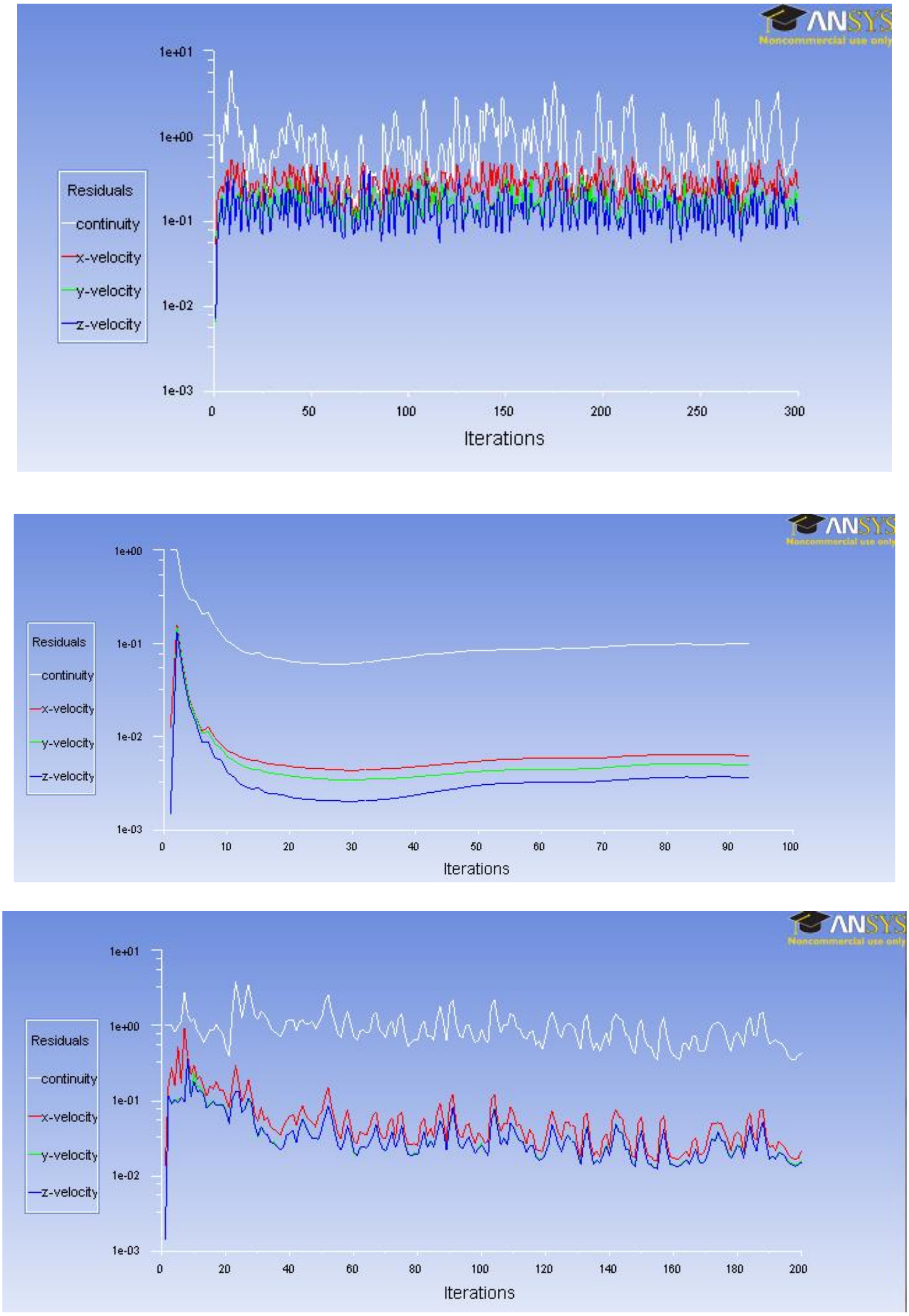

Fig. 6. Convergence of Navier-Stokes equations residual for compression

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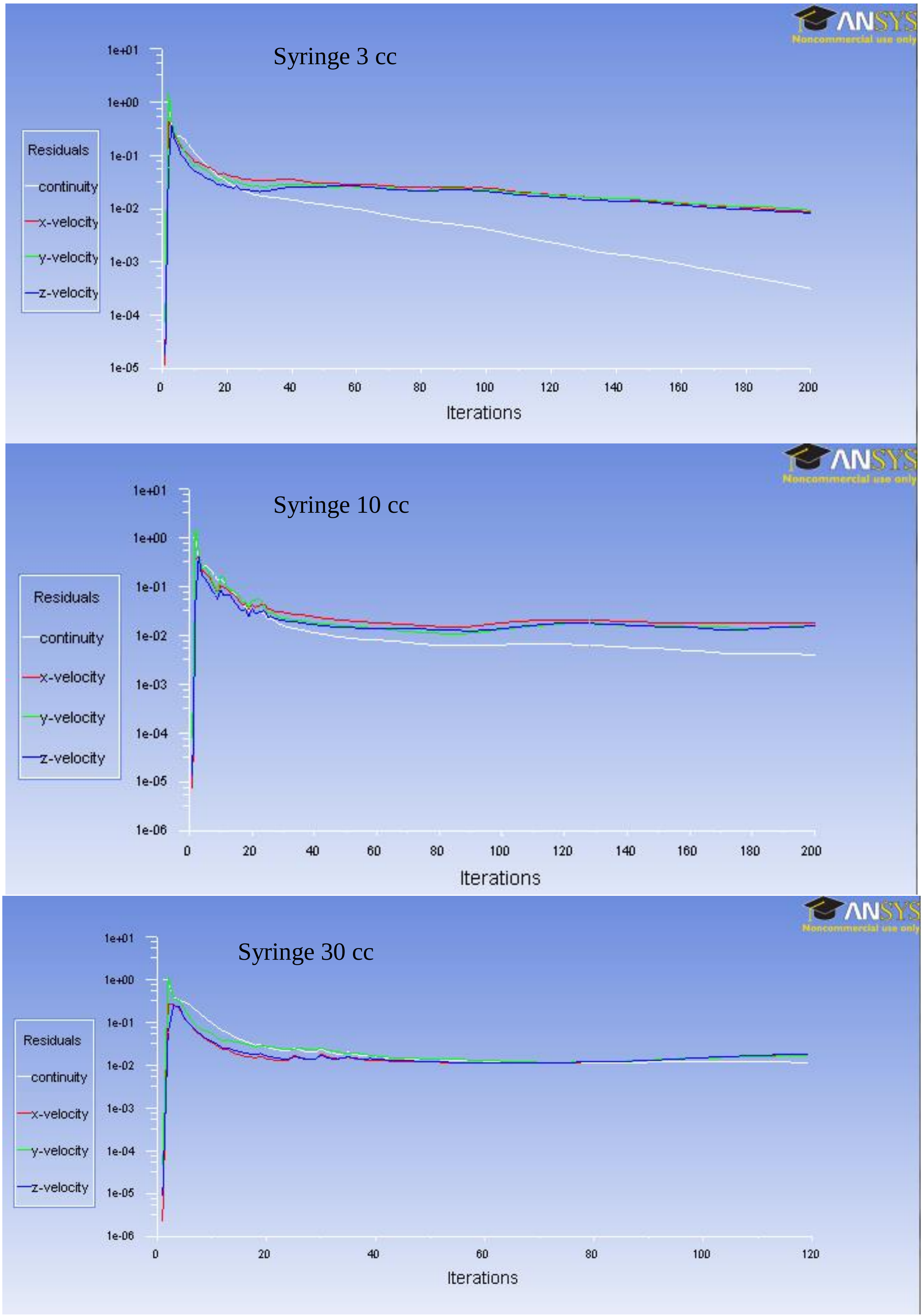

Fig. 7. The convergence of Navier-Stokes equations residual for suction.

5. CONCLUSION

A comprehensive CFD study, using Ansys-Fluent code, has been conducted. The study was split into three cases: 1) compression-suction 3CC, 2) compression-suction 10CC, and 3) compression-suction 30CC. This study was performed to analyze the impact of: the syringe diameter, the fluid viscosity on the mass flow and pressure distribution along the syringe connected to the three way valve. The syringes 30 cc and 3 cc have a major impact on the velocity profile as it can be noticed from above results. On the other hand, increasing the fluid viscosity increases the travel force of the flow in the compression system and affects the flow pattern in the system. However, the syringe diameter has insignificant impact on the pressure contour along the suction system as shown in above figures. Future work includes improving the CFD analysis methodology. A more thorough grid refinement study, for example performing several grid adaptation cycles, should be attempted on one of the geometries to determine an optimal grid size. An unsteady multistage analysis is recommended to properly capture the flow at the interface between the end of syringe and the valve and for better understanding the vortex flow in the cavity of the syringe.

Nomenclature

Q =Volumetric flow rate
μ =Fluid viscosity
L=Needle length
R=Needle inner diameter
A=Cross sectional area of syringe plunger
F = Frictionless travel force
Re = Reynolds number
V = tangential velocity, m/s

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