Abstract: In this contribution we present the results of the numerical modelling and performance optimization study of a diaphragm pump for drug infusion. The main objective is to develop a numerical model that replicates the pumping cycle (400ms) and also provides indications about the variation of pumping performance as consequence of the variation of the chamber-diaphragm system geometry, diaphragm materials and other operating conditions (backpressure and pumping fluid). In the first part a brief description of the pump, computational domain, boundary conditions and governing equations of the model will be presented. The structural behaviour of the diaphragm subjected to the forces of the electromagnetic actuation system will be shown. In particular the effect of the different diaphragm material and the stress state with different geometry will be analyzed. The fluid dynamic effect of the diaphragm movement will be transferred to the fluid inside the pumping chamber and then at intake-exhaust system. The results of the numerical simulations will be showed in order to identify the relevant geometrical parameters and select the best solution in order to improve of the pumping performance.

Results: The numerical characteristic curves of the pump have been obtained by imposing the boundary conditions for the different operative conditions (backpressure and pumping fluid: water and viscous fluid). The pump oscillations, provided by the constructor, performed by the diaphragm. The pump flow rate is proportional to the number of strokes of the electromagnetic system for each single injection. The geometry of the pump was supplied by constructor and is illustrated in Figure 1.

Effect of different diaphragm materials: The choice of the material does not substantially affect the diaphragm active area, i.e. the zone where the deformation is useful for the pumping effect. In Figure 5 the active area for the molded geometry with different materials is shown in comparison with a flat geometry. The area also extends to the decrease in operating pressure. The PTFE membrane showed a less maximum value of the Von Mises stress in comparison with PVDF membrane. This result is very important in order to assess the reliability of the membrane and the ability to trigger cracks in the central area and the connection between the stem and diaphragm.

Computational domain and boundary conditions: Based of the geometrical and operative details provided by the constructor (Figure 1), the 3D structural and fluid domain of the pump has been reproduced. The mesh, represented in Figure 2, is composed of about 9400 tetrahedral elements. Constant pressure boundary conditions are imposed for inlet and outlet of the fluid domain and an inlet velocity is imposed, i.e. a fluid is assumed to be water (density \( \rho = 1000 \text{ Kg/m}^3 \)). The diaphragm elastic behaviour has been assessed using COMSOL Structural Mechanics Model. The deformation of the diaphragm has been modelled by using COMSOL Structural Mechanics Model. The diaphragm material is sealed to the pumping chamber. The radius of curvature (R) of the diaphragm has been evaluated taking into account the variation of the geometry of the chamber-diaphragm system, materials and operating conditions. The present molded configuration, the configuration with a totally flat diaphragm, and an optimized molded configuration (molded-upgrade) have been designed (see Figure 4) in order to minimize at top dead center the distance (H2) between the top of the pumping chamber and diaphragm and (H2) that the pump is sealed to the pumping chamber. The radius of curvature (R) of the diaphragm has been changed in order to obtain a spherical configuration at the top dead center. In such deformation condition the dead volume can be minimized and the stress distribution can be more regular.

Figure 2: Computed domain (top left) pumping chamber (top right) and valves (bottom).

Figure 3: Pressure and velocity field inside the pumping chamber for the standard molded geometry during the pumping cycle (0-0.036s-0.156s-0.4s).

Figure 4: Relevant dimensional parameter for the geometrical optimization.

Figure 5: Active area for different diaphragm (standard molded) materials: PVDF (top left), PTFE (top right) compared to a flat PTFE diaphragm (bottom).

Figure 6: Characteristic curves for different standard molded, flat and molded-upgrade diaphragm compared to the experimental data.

Figure 7: Vorticity field inside the pumping chamber (0-0.036s-0.156s-0.4s).

Figure 8: Characteristic curves for different standard working fluid: water and viscous fluid.

Figure 1: The diaphragm pump geometry (not to scale). Inlet/outlet valves (in red), pumping chamber and diaphragm are represented.