Materials engineering
Department of polymers and
petrochemical industries

Republic of Iraq
Ministry of higher education
and scientific research
University of Babylon

[Numerical Simulation of Production of Microspheres from Polymer Emulsion]

A graduation project is submitted to the Material's Engineering College in partial fulfillment of the requirements for the degree of Bachelor of Science in Polymers and Petrochemicals Industries

Prepared By :

Sajad Abd Alabbas Mohammed

Supervisor :

Prof.Dr. Nizar Jawad

2023_2022

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلاً

صدق الله العلي العظيم

الإسراء : الآية٨٥

الإهداء

إلى من نمتُ في دفئ سنينها وسهرت عليَّ بحنينها وإلى من كد وشقي من اجلي (أميوأبي العزيزين)

إلى سندي في هذهِ الحياة إخوتي الأعزاء.

إلى من سرنا سوياً ونحن نشق الطريق إلى النجاح

إلى من تكاتفنا يداً بيد لنقطف ثمار تعلمنا إلى جميع الأصدقاء.

أهديكم ثمرة جهدي هذا

الشكر والتقدير

لا بد لي وأنا اخطوا خطواتي الأخيرة لنيل شهادة البكالوريوس

من وقفة أعود بها إلى الأعوام قضيتها في رحاب الجامعةمع أساتذتي الكرام الذين قدموا الكثير باذلين جهود كبيرة في بناء جيل الغد . وقبل ان امضي, أقدمأسمىآيات الشكر والامتنان والتقدير والمحبة للذين حملواأقدس رسالة في الحياة.إلى جميع أساتذتنا الكرام في كلية هندسة المواد جامعة بابل.وأخص بالتقدير والشكر والامتنان إلى الأستاذ المشرفعلى هذا

المشروع د. نزار جواد لما قدمهُ لي من ملاحظات ونصائح علمية قيمة وأرشدني بتوجيهاته لأنجاز هذا المشروع.

Contents :

الخلاصة :

النمذجة العددية لها دور كبير في تقليل الجهد والوقت للوصول الى افضل النتائج . أجهزة الميكروفلوديك تستخدم للخلط ، والفصل ، وتوصيل الدواء ، وتشكيل الكرات المجهرية. حيث تم استخدام مستحلب البوليمرات الحيوية في لإنتاج كريات مجهرية ممكن ان تحمل بانواع مختلف من الأدوية لاستخدامها في نظام توصيل الدواء. إن محاكاة مستحلب البوليمر في التحكم في إنتاج الكريات المجهرية هو اختبار عددي للتنبؤ بإنتاج الكرات المجهرية أثناء تدفق المستحلب في المايكروفلويدك تم دراسته ببرنامج ثنائي البعد ANSYS (Workbench16.1).

ان المحاكاة التي أجريت بدراسة تأثير اللزوجة والكثافة والسرعة والتوتر السطحي والشكل الهندسي مهمة جدًا للتحكم في حجم والشكل وتوزيع وكمية الكرات.

اثبتت النتائج انه مع زيادة السرعة ، انخفض حجم الكرات وأعطى شكلاً كرويًا ، بينما أصبح نظام التنقيط هو السائد. كذلك ادى انخفاض الكثافة واللزوجة والتوتر البيني وتغيير الشكل الهندسي، إلى انخفاض حجم الكرات. نظام القطيرات من نوع التنقيط هو السائد لجميع المؤثرات باستثناء انخفاض التوتر السطحي ، حيث ان نظام النفث هوالذي ساد فيه بشكل واضح

Abstract :

Numerical simulation has a great role in reducing effort and time to reach the best results. Microfluidic devices have been developed for Mixing, separation, drug delivery, and microspheres formation .Biopolymers emulsion can be used in microfluidic to produce microspheres. These microspheres loaded with different type of drug in order to use in drug delivery system.Optimizing of the polymer emulsion in controlling on microspheres production is very difficult test experimentally.Therefore predict the microspheres productionby model during emulsion flow through microfluidic device was studied numerically using 2D ansys software.

Simulation performed due to the effect of viscosity,density,velocity,surface tension and geometry was very important to control on the shape size,distribution,quantity of microspheres.

The results show that the increasing in velocity, decreases the size of the microsphere and gave a spherical shape, and the dripping regime became dominant. With the decreasing in density, viscosity, interfacial tension and geometry, decreasing in the size of the microsphere was obtained. The regime of droplet of dripping type was observed for all parameters except for the interfacial tension effect , which is the jetting regime is clearly dominant.

Keywords:

Microspheres, polymer flow, Microfluidic Numerical simulation,

Chapter one

Introduction

Introduction :

Simulation and modeling are very strong tools to design and simulate engineering cases that can be difficult to ably experimentally. In microscale domains, simulation and modeling play a very strong role to maintain results for specific cases that are hard to explain.Microsphere refers to spherical microparticles with a diameter of 1–1000 μm. Biodegradable polymers are frequently used for the development of microsphere matrixes such as polylactic acid and copolymer of lactic acid and glycolic acid. Apart from them, there is an extensive range of microspheres prepared from albumin, albumin dextran sulfate, and fibrinogen. Administration of medication via microparticulate systems is advantageous because microspheres can be ingested or injected; they can be tailored for desired release profiles and used for site-specific delivery of drugs and in some cases can even provide organ-targeted release. So far, a series of phytomedicines such as rutin, camptothecin, zedoary oil, tetrandrine, quercetin and Cynarascolymus extract have been successfully exploited through this delivery system. In addition, reports on immune microsphere and magnetic microsphere are also common in recent years. Microspheres and microparticles are polymer particles produced on a micron scale, capable of releasing a preloaded drug that has been incorporated into a central reservoir . polymer microspheres are one of the most types common and hold several advantages including encapsulation for many types of drugs such as small molecules, proteins, and nucleic acids.

Experimentally, in a study conducted byRoaa Mohammed Muneer , Prof. Nizar Jawad Hadi , Prof. Ali Al-Zubiedy starch microspheres were formed with a different shape ranging from oval to spherical shape.To understand the shape changing, a numerical simulation study has been introduced using (ANSYS workbench 16.1) program, to simulate and study the microspheres formation process and the effect of flow rate varying on microspheres formation. where the numerical results showed an excellent agreement with experimental results. The microspheres formation process and the breakup mechanism contours were very similar to the breakup mechanism in experimental work.

In another study.Polymeric double-walled microspheres were developed by coaxial electrohydrodynamic atomization (CEHDA) and precision particle fabrication (PPF) techniques. Here, we focus on double-walled microspheres consisting of a poly (D, L-lactic-co-glycolic acid)(PLGA) core surrounded by a poly (D, L-lactic acid)(PDLLA) or poly (L-lactic acid)(PLLA) shell layer.The first study involves bridging the experimental work on the fabrication of double-walled microspheres from CEHDA and the simulation work on the generation of compound droplets from the same process. Process conditions and solution parameters were investigated to ensure the formation of doublewalled microspheres with a doxorubicin-loaded PLGA core surrounded by a relatively drug-free PDLLA shell layer.

Numerical simulation of CEHDA process was performed based on a computational fluid dynamics (CFD) model in Fluent. The simulation results were compared with the experimental work to illustrate the capability of the CFD model to predict the production of consistent double-walled microspheres.

In another study .The oil phase in oil-in-water (O/W) emulsions was 1 wt% polycaprolactone (PCL, Mw = 14,000 g mol-1,) dis-solved in dichloromethane (DCM, HPLC grade, Fisher Scientific. The oil phase in water-in-oil-in-water (W/O/W) emulsions was a mixture of 1–3 wt% poly(DL-lactic acid) Polysciences, or polycaprolactone (PCL,Mw = 14,000 g mol-1,) dissolved in dichloro- or 1:2 mixture of chloroform and toluene. 5–10 wt% polyglycerol polyricinoleate was added in the oil phase to prevent coalescence of inner water droplets, Monodispersed polycaprolactone and poly(lactic acid) particles with a diameter of 18– 150 lm were produced by evaporation of solvent (dichloromethane or 1:2 mixture of chloroform and tol-uene) from oil-in-water or water-in-oil-in-water emulsions produced in three-dimensional flow focusingglass capillary devices. The drop generation behaviour was simulated numerically using the volume of fluid method.

The numerical results showed good agreement with high-speed video recordings. Monodi-spersed droplets were produced in the dripping regime when the ratio of the continuous phase flow rate to dispersed phase flow rate was 5–20 and the Weber number of the dispersed phase was less than 0.01.

Synthetic polymeric microspheres find application in a wide range of medical applications. Among other applications, microspheres are being used as bulking agents, embolic- or drug-delivery particles. The exact composition of the spheres varies with the application and therefore a large array of materials has been used to produce microspheres.

ANSYS:

ANSYS is an American public company headquartered in Cannesburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test product durability, temperature distribution, fluid motions, and electromagnetic properties. Ansys was founded in 1970 by John Swanson.Ansys program is concerned with solving linear and nonlinear problems for: structural mechanics, fluid mechanics, acoustics, thermodynamics, piezoelectricity and classical electromagnetism. The program contains a number of elements for solving one-dimensional, twodimensional and three-dimensional problems.

ANSYS is a general-purpose, finite-element modeling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic, structural analysis, heat transfer, and fluid problems, as well as acoustic and electromagnetic problems. Ansys simulation gives engineers the ability to explore and predict how products will work — or won't work in the real world. Ansys gives the tools to tackle the complexities of designing, manufacturing and maintaining products and processes. can expand simulation activities throughout product lifecycle, from design validation to exploring the “what ifs” of products, facilitating innovation, lowering development and operational costs and improving time to market.

A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physicalproperties. Finally, the Ansys software simulates and analyzes movement ,fatigue, fractures, fluid flow, temperaturedistribution, electromagnetic efficiency and other effects over time.

Other software that depend on finite element

1. **Abaqus 2- mat lap 3- Comsol 4- Nastran**

Computer specification :-

Processor : Intel(R)Core™i5-3210M CPU @ 2.50GHz 2.50 GHz

Installed memory (RAM) : 4.00 GB

System type : 64-bit Operating System

Numerical Methods:

1-Finite element:

The finite element method (FEM) is a popular method for numerically solving differential equations arising in engineering and mathematical modeling. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

The finite element method is a numerical method like the finite difference method, but is more general and powerful in its application to real-world problems, which may involve multi-physics and complicated geometry and boundary conditions. In the finite element method, a given domain is viewed as a collection of subdomains, and over each subdomain the governing equation is approximated by any of the traditional variational methods or any method that is suitable. The main reason behind seeking approximate solutions on a collection of subdomains is the fact that it is easier to represent a complicated function as a collection of simple polynomials.Engineers develop conceptual and mathematical models of phenomena and sys- tems that they wish to understand. The understanding may be used to develop and improve systems that contribute to the human convenience and comfort. Mathematical models are developed using axioms and laws of nature that govern the phenomena. Mathematical models consist of algebraic, differential, and/or integral equations, and they are readily available for most problems in textbooks. Differential and integral equations are often difficult to solve exactly for the desired quantities of the system for a variety of input parameters (called data), necessitating the use of numerical methods. In the numerical simulations of physical processes, we employ a numerical method and a computer to evaluate the mathematical model of the process. The finite element method is a powerful numerical method of solving algebraic, dif- ferential, and integral equations, and it is devised to study complex physical processes.

The method is characterized by three basic features:

1. The domain of the problem is represented by a collection of simple subdo-mains, called finite elements. The collection of finite elements is called the finite element mesh.

2. Over each finite element, the physical process is approximated by functions of desired type (polynomials or otherwise), and algebraic equations relating physical

quantities (duality pairs) at selective points, called nodes, of the element are developed. The set of algebraic equations is called a finite element model.

3. The element equations are assembled using continuity and "balance" of the physical quantities in the model.

Computational fluid dynamic (CFD) simulation is a powerful tool in the design and implementation of microfluidic systems, especially for systems that involve hydrodynamic behavior of objects such as functionalized microspheres, biological cells, or biopolymers in complex structures computational fluid dynamic (CFD) simulations coupled with solid mechanics have become an increasingly important tool. By incorporating the complexities of its parameters, the microfluidic system's hydrodynamic behavior can be predicted and visualized, even though the system's minute dimensions make them difficult to prove via explicit mathematical methods or experiments. Therefore, the simulations help researchers assess design alternatives at reduced cost and guide experimental operation. For a particle-based target detection platform19 as an example, microspheres with receptors on their surfaces to capture biological targets (DNAs, RNAs, or proteins) are immobilized by the trap arrays through microfluidic techniques. The trap array geometry must be rationally designed to maximize the trapping efficiency of microspheres and minimize fluidic errors (i.e., traps that are occupied by no or multiple microspheres, or traps with clogged channels). The importance of hydrodynamic property in the successful trapping of the microspheres, highlighted the value of CFD simulations in predicting and investigating the movement of microspheres in the microfluidic device.

2-Finite volume:

The finite volume method is a discretization method which is well suited for the numerical simulation of various types (elliptic, parabolic or hyperbolic, for instance) of conservation laws; it has been extensively used in several engineering fields, such as fluid mechanics, heat and mass transfer or petroleum engineering.

Similar to other numerical methods developed for the simulation of fluid flow, the finite volume method transforms the set of partial differential equations into a system of linear algebraic equations. Nevertheless, the discretization procedure used in the finite volume method is distinctive and involves two basic steps. In the first step, the partial differential equations are integrated and transformed into balance equations over an element. This involves changing the surface and volume integrals into discrete algebraic relations over elements and their surfaces using an integration quadrature of a specified order of accuracy. The result is a set of semidiscretized equations. In the second step, interpolation profiles are chosen to approximate the variation of the variables within the element and relate the surface values of the variables to their cell values and thus transform the algebraic relations into algebraic equations.

The accuracy of numerical simulation algorithms is one of main concerns in modern Computational Fluid Dynamics. Development of new and more accurate

mathematical models requires an insight into the problem of numerical errors. In order to construct an estimate of the solution error in Finite Volume calculations, it is first necessary to examine its sources. Discretisation errors can be divided into two groups: errors caused by the discretisation of the solution domain and equation discretisation errors. The first group includes insufficient mesh resolution, mesh skewness and non-orthogonality. In the case of the second order Finite Volume method, equation discretisation errors are represented through numerical diffusion. Numerical diffusion coefficients from the discretisation of the convection term and the temporal derivative are derived.

Finite element methods are widely used by the numerical analysis community to study numerical methods for fluid flow. There is a vast amount of work described in scientific publications regarding CFD and finite element methods as well as more recent work for nodal discontinuous Galerkin (DG) methods, which are finite element methods with discontinuous basis functions.Commercial packages for CFD are traditionally based on finite volume methods. This is due to the fact that basically all of the larger commercial packages for CFD have the same ancestors. There is a vast amount of work and technology invested in these methods in the industry. Different methods have been implemented so that they can efficiently and accurately compute and integrate the fluxes for both structured (for example, hexahedrons; i.e., bricks) and unstructured (for example, tetrahedrons) meshes.

Chapter two

mathematical models

Governing Equations:

Momentum equation:

The momentum equation is a mathematical formulation of the law of conservation of momentum.

given by Eq.(general fluid)

$$\rho\left(\frac{\partial \boldsymbol{V}}{\partial t}+\boldsymbol{V}\cdot\nabla\boldsymbol{V}\right)=-\nabla p+\mu\nabla^{2}\boldsymbol{V}+\rho\boldsymbol{g}$$

Continuity equation:

continuity equation is an equation that describes the transport of some quantity. It is particularly simple and powerful when applied to a conserved quantity.

given by Eq.(general fluid)

$$\frac{\partial \rho}{\partial t}+\rho(\nabla\cdot\underline{v})+\underline{v}\cdot\nabla\rho=0$$

incompressible fluids

$$(\partial \rho /\partial t) = 0$$

Classification of flow types:

1-Newtonian flow: flow at constant viscosity with increasing of shear rate, such as (water, molten metal, and simple organic liquids).

$\tau = \mu\gamma$

τ is the shear stress (pa).

2-Non-Newtonian flow: flow with variable viscosity with increasing of shear rate, such as (polymer melts or solutions, paints, bloods, and some

foods and drugs).

$\tau = \mu\gamma$^n

n is the flow index.

The polymer material is a viscoelastic material their behavior between

elastic solid and viscous fluid.

The non-Newtonian flow types:

1_Shear thinning flows : The viscosity decreases with the increasing of shear rate. The most important behavior of non-Newtonian flow of polymer melts or solutions. The viscosity decreases due to the orientation, disentanglement, and alignment of chains.

2_Shear thickening flows: The viscosity increases with the increasing of shear rate during some polymers flowing, such as (starch, suspension, and pastes).The viscosity increases due to the decreasing in liquids with the increasing shear rate. This make it unable to fill the void space and direct solid-solid contact occurs. This mechanism produces high friction and viscosity.

2_Viscoplastic flow (Bingham): This type of flow behavior is characterized by existence of a yield stress , which must be exceeded before the fluid is flow. This flow regard as shear thinning behavior

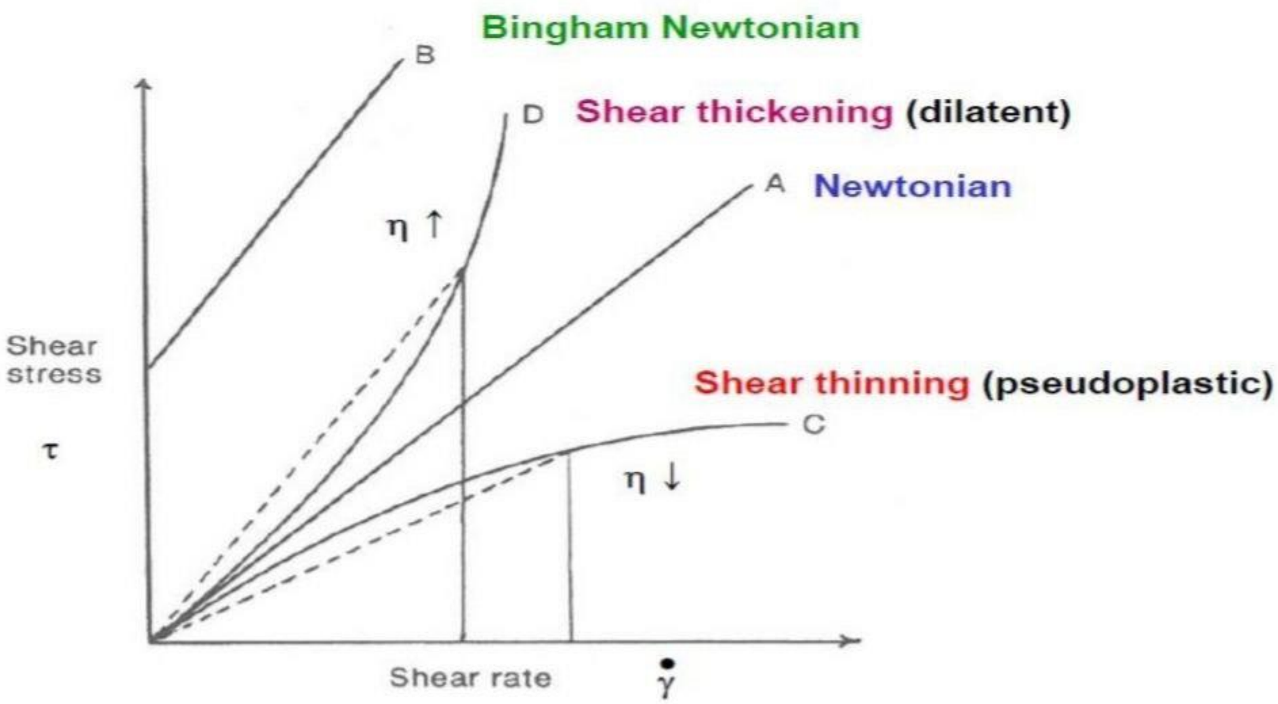


Fig.1: Types of shear flow

Mathematical Models:

There are many models used in the flow of non-Newtonian flow according to the flow behavior.

Power law Models:

The flow properties of polymer melts can be represented by log curves (τ) and (η) versus (γ) Many models of varying compexity and form have been proposed. Some of these models are direct curve fitting of shear stress vs. shear rate experimental data.

Power law or Ostwald de Waale model :

Non-linear shear stress vs. shear rate curve of shear thinning fluids can be represented by power law models as give bellow :

τyx = m(γ)n

m and n are two empirical curve fitting parameters.

n is power law fluid behavior index (dimensionless)

n<1 indicate shear-thinning behaviour of fluid (0<n<1)

n=1 indicate Newtonian fluid behaviour m is powerlaw

fluid consistency index (Pa.s)

At low shear, the randomizing effect of the thermal motion of the chain segments overcomes any tendency towards molecular alignment in the shear field -random state- greatest resistance to flow

As the shear increased, the molecules will begin to untangle and align in the shear field, reducing their resistance to slippage past one another

Under severe shear, they will be completely untangled and aligned and reach a minimum state of resistance to flow. Further intense shearing eventually leads to extensive hreakage of main-main bonds mechanical degradation.

Most commercial polymer processing is done in regions of the viscosity versus shear rate curve where the viscosity is decreasing with shear rate. Such flow behavior is pseudoplastic (shear thinning) and can be can be described by the power law equation τ= K (γ)n where K= consistency index [Pa.sn] - Typical values 1,000-100,000 Pa.sn n= power-law index (dimensionless] - Typical values 0.2-0.8.

For a shear thinning fluid is between zero and 1. The more shear thinning the product the closer is to zero.

In logarithmic form the power law equation may be written as When **log(τ) = log k +n log(γ)** n=1 , the fluid is Newtonian n1 implies that the fluid is dilatant [3] Equation relating viscosity to shear rate for apower law fluid is given bellow:-

$$\tau = \eta(\dot{\gamma})\dot{\gamma} \qquad (1)$$

$$\eta(\dot{\gamma}) = \frac{\tau}{\dot{\gamma}} \qquad (2)$$

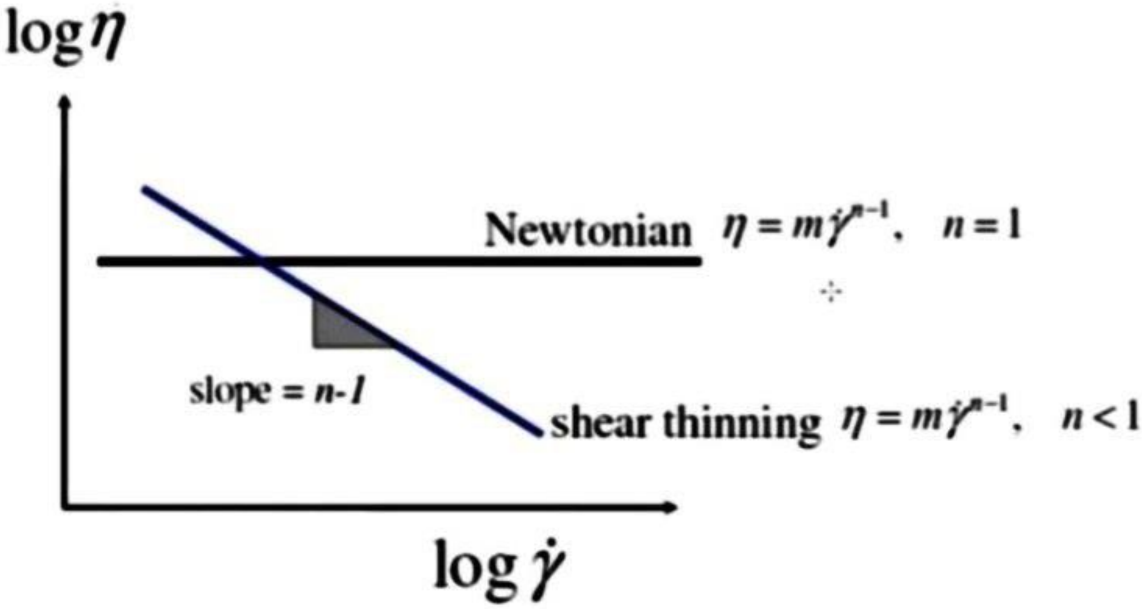
$$\tau = K(\dot{\gamma})^n \qquad (3)$$

$$\eta(\dot{\gamma}) = \frac{K(\dot{\gamma})^n}{\dot{\gamma}} \qquad (3) \text{ in } (2)$$

$$\eta(\dot{\gamma}) = K(\dot{\gamma})^{n-1}$$ **Viscosity function**

$$\log \eta(\dot{\gamma}) = \log K + (n-1)\log \dot{\gamma}$$

Thus alog - log plot of n vs. γ for apower law fluid is linear with aslope of n1 therefore n=slop +1



Although the power law model accurately represents the pseudoplastic region, it neglects the Newtonian plateau at small and large strain rates.
The viscosity goes to infinity at low strain rates and zero at high strain rates.

This limits the use of the power law model in predicting the flow behavior of polymeric materials.

Direct numerical simulation of the weakly turbulent flow of non-Newtonian fluids with shear-thinning rheology are undertaken. Results agree reasonably well with the experimentally determined logarithmic layer correlation presented by Clapp (1961) and with other previously published experimental work. As the power law index becomes smaller for the same Reynolds number, the flow deviates further from the Newtonian profile and the results suggest that transition is delayed. Use of this technique shows promise in understanding transition and turbulence in non-Newtonian fluids.

Parameters effect on the Microspheres specifications:

Velocity, Viscosity, Density, Geometry, and Surface tension.

Dimensionless Groups: There is many dimensionless groups used in study and comparison between the effects of different parameters on microspheres.

capillary number

The capillary number is defined as the ratio of viscous to interfacial forces and is used to study the microscopic displacement of the polymer.

given by Eq.

$$Ca = \frac{\mu\, v}{\gamma}$$

where:

μ = fluid viscosity [=] g / (m s)

v = velocity [=] ft / s

Weber number

Weber number is the ratio of inertia force to the surface tension. The formation of droplets or water bubbles in a fluid is normally due to surface tension. If Weber number is small, surface tension is larger and vice versa.

given by Eq.

$$W_e = \frac{\rho . d . v^2}{\sigma}$$

Where,

ρ = Density of fluid (kg/m^3)

σ = Surface tension of fluid (N/m)

d = diameter of water droplet (m)

v = velocity of flow (m/s)

Reynolds number

Reynolds number is the ratio of inertia force to the viscous force. It describes the predominance of inertia forces to the viscous forces occurring in the flow systems.

given by Eq.

$$R_e = \frac{\rho . v . d}{\mu}$$

ρ = Density of fluid (kg/m^3)

μ = viscosity of fluid (kg/m.s)

d = diameter of pipe (m)

v = velocity of flow (m/s)

Regimes of droplet (Microspheres)formations:

Numerical and experimental studies showed that different regimes of droplet formations in microchannels mayoccur. These regimes include squeezing, transition, dripping, jetting and parallel flow regimes.

dripping regime:

In the dripping regime, the formed droplet size is smaller than the main channel width. Therefore, it does not occupy the whole of the channel width. In this regime, droplet size highly depends on the capillary number and viscosity forces that play an important role in the droplet formation.

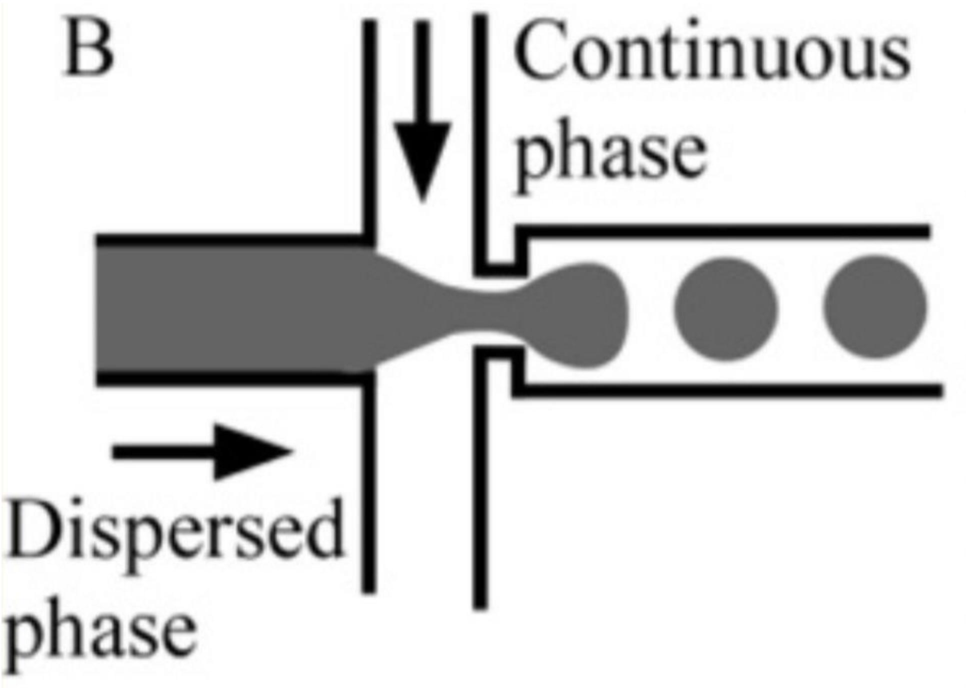


Fig.2:dripping regime

jetting regime:

In the jetting regime, aliquid jet spans part of the microchannel, and few dropletsare produced at the end of the jet. As the capillary number increases, the flow pattern changes to the parallel flowwithout a droplet formation.

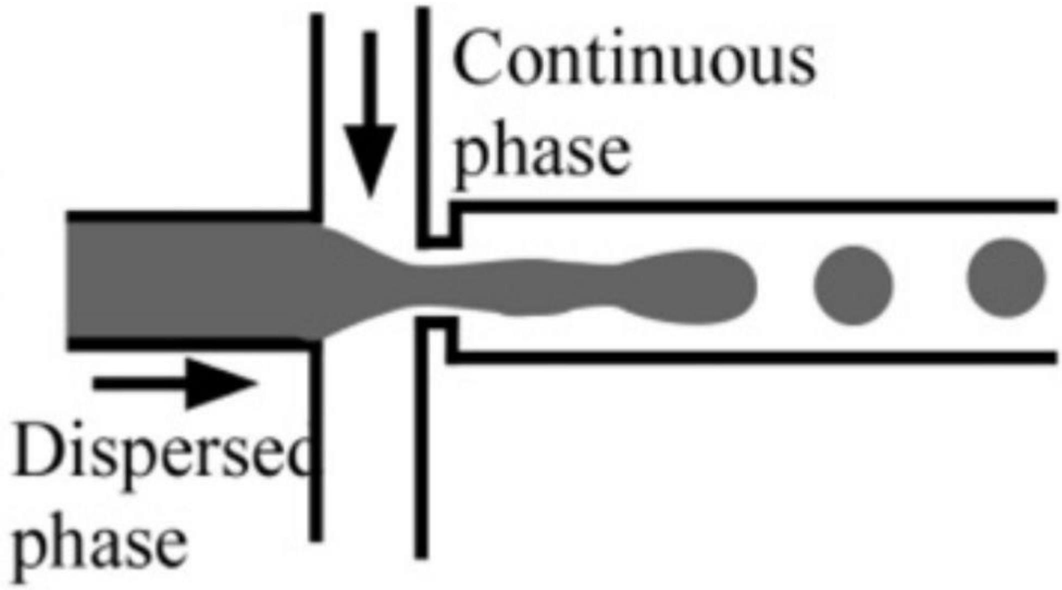


Fig3:jetting regime

The production of droplets in microfluidics requires at least two fluid phases, where physical variables of the fluids, such as interfacial tension (γ) and viscosities of the dispersed (μ_d) and continuous phases (μ_c) are necessary to characterize the generation of droplets. In addition, external parameters such as flow rates of the dispersed (Q_d) and continuous phases (Q_c), and channel dimensions (w and h) play important roles. In the case of large flow velocities where inertia starts to have an effect, the densities of the dispersed (ρ_d) and continuous phases (ρ_c) also become relevant. To understand the dynamics of the generation of droplets and particularly to obtain quantitative scaling laws of the droplet volume and generation frequency for a specific flow regime, a suitable choice of dimensionless numbers, which are typically the product or ratio of the physical parameters mentioned above, is desired.

The balance between local shear stresses and capillary pressure is conveniently captured by the dimensionless continuous phase and dispersed phase capillary numbers, $Ca_c = \mu_c U_c/\gamma$ and $Ca_d = \mu_d U_d/\gamma$, and the relative dominance of fluid inertia to capillary pressure is similarly modeled using the dimensionless Weber number. *Ca* is the most important dimensionless number for microfluidic droplet formation and its value is typically around 10^{-3}–10. *We* is an important dimensionless number when inertial effects start to matter, for example at the onset of jetting in coaxial devices. These dimensionless parameters help in the prediction of resulting drop or jet formation and are also useful for designing experiments. For example, to suppress instabilities in a two-phase microfluidic system and produce jets, it is possible to increase the flow speeds or the ratio of viscosity to interfacial tension in the system to increase the capillary numbers.

In addition to the capillary and Weber numbers, the ratio of volumetric flow rates between the dispersed phase and the continuous phase, Q_d/Q_c, the viscosity ratio of the two phases, μ_d/μ_c, and the geometrical aspect ratios of the dispersed and continuous phase channel width and height, h/w, are often cited in the literature to capture the various dynamics that promote or inhibit instabilities.

So

d α 1/Ca

d α $\gamma/\eta_{out}.\ \mu_{out}$

Chapter three

Results and discussion

Results and discussion

The formation of microspheres was simulated from a microfluidic system by the ANSYS(Workbench16.1) , where a two-dimensional shape was obtained to form a microsphere.Thelength of plate is (1260 nm) and the width is (480 nm). The effect of density, velocity, viscosity, surface tension, and geometry on the microsphere were studied. Table 1 shows the properties for each phase.

Table 1: Experimental properties of continuous and dispersed phases.

	Density kg/m3	Viscosity kg/m-s	Velocity m/s	Contact angle	Interfacial tension N/m
Water phase	998	0.00103	0.015	175	0.006
Oil phase	1470	0.00303	0.015		

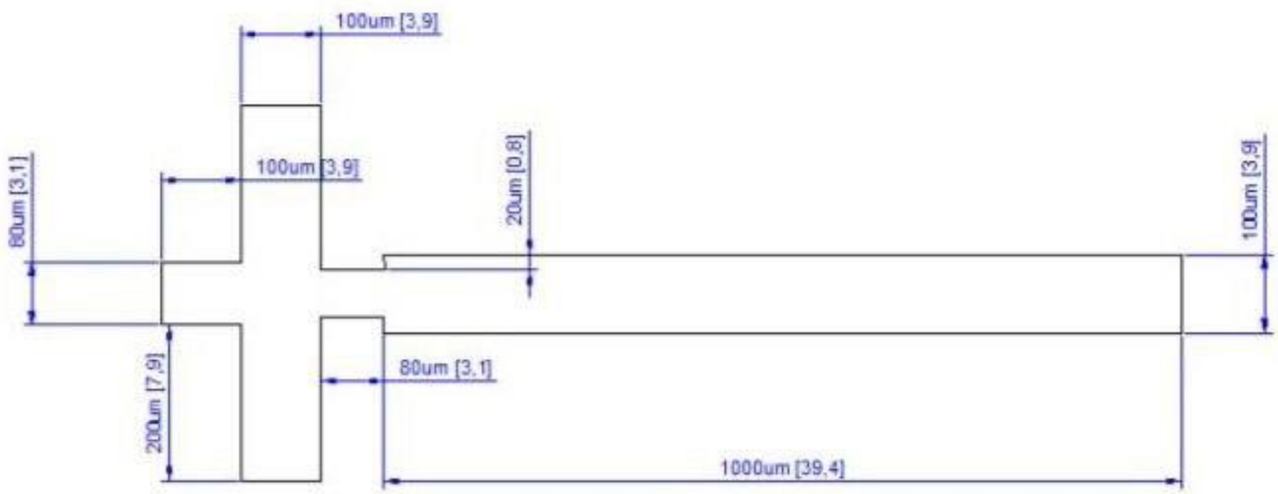
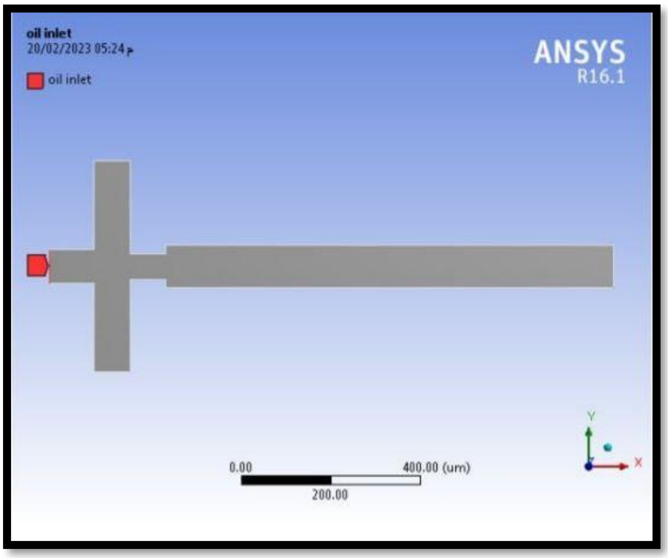
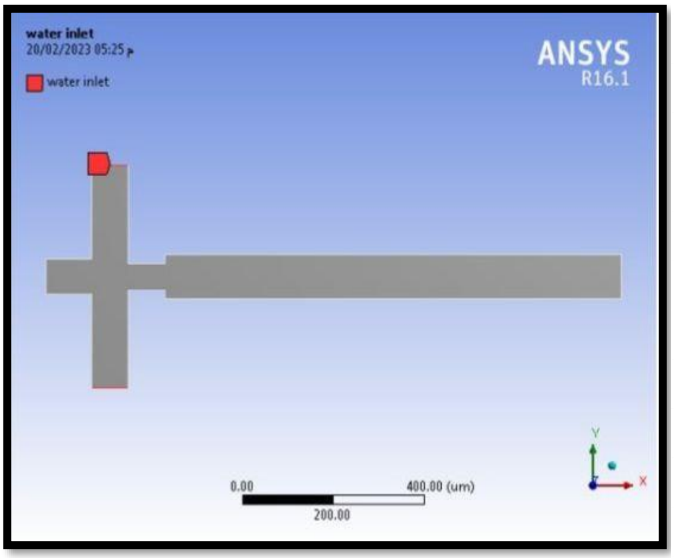


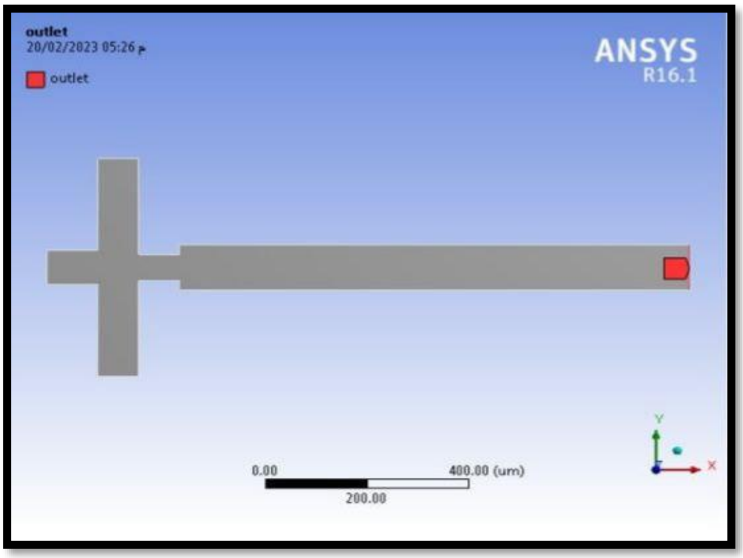
Fig 1. 2D geometry of microfluidic device by Autocad.



(a)



(b)



(c)

Fig 2: The boundary conditions used in this study (a) inlet oil phase. (b) inlet water phase , (c) outlet microspheres.

.

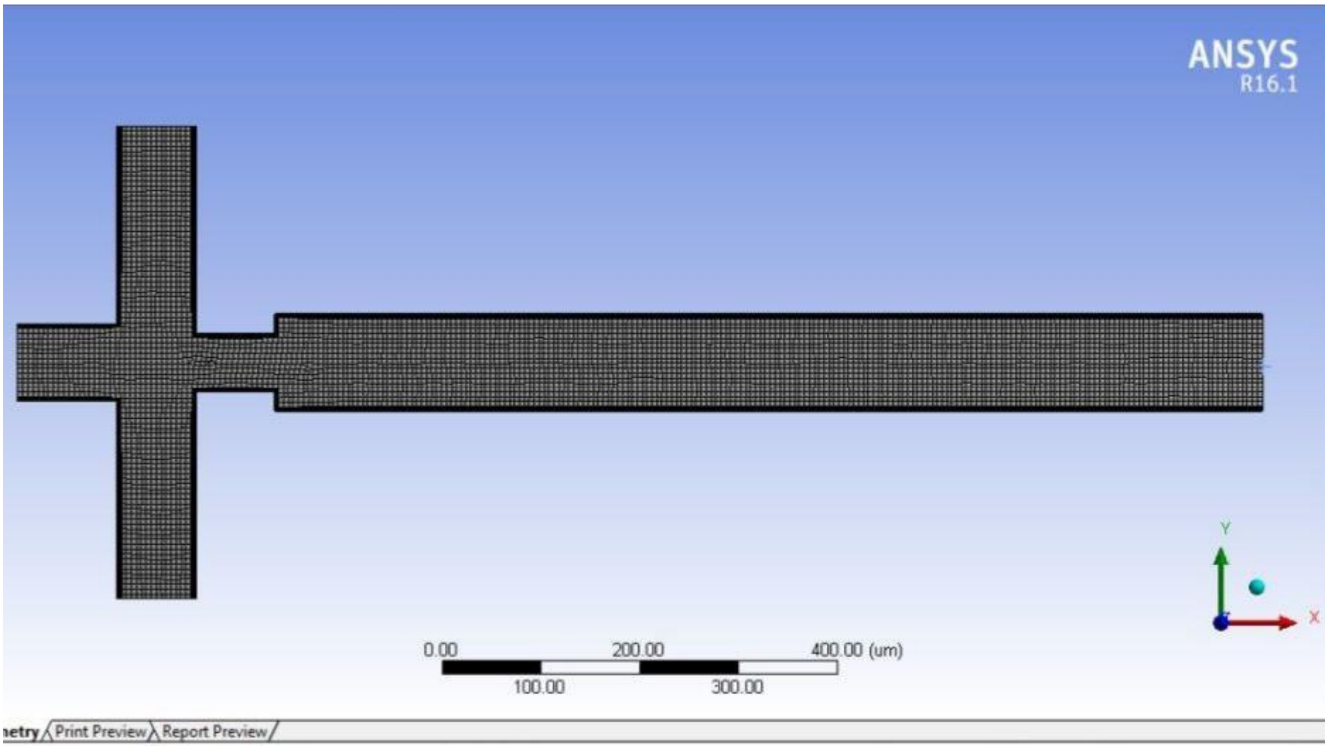


Fig.3. the mesh of 2D microfluidic, which contains 8583 elements and 8955 nodes.

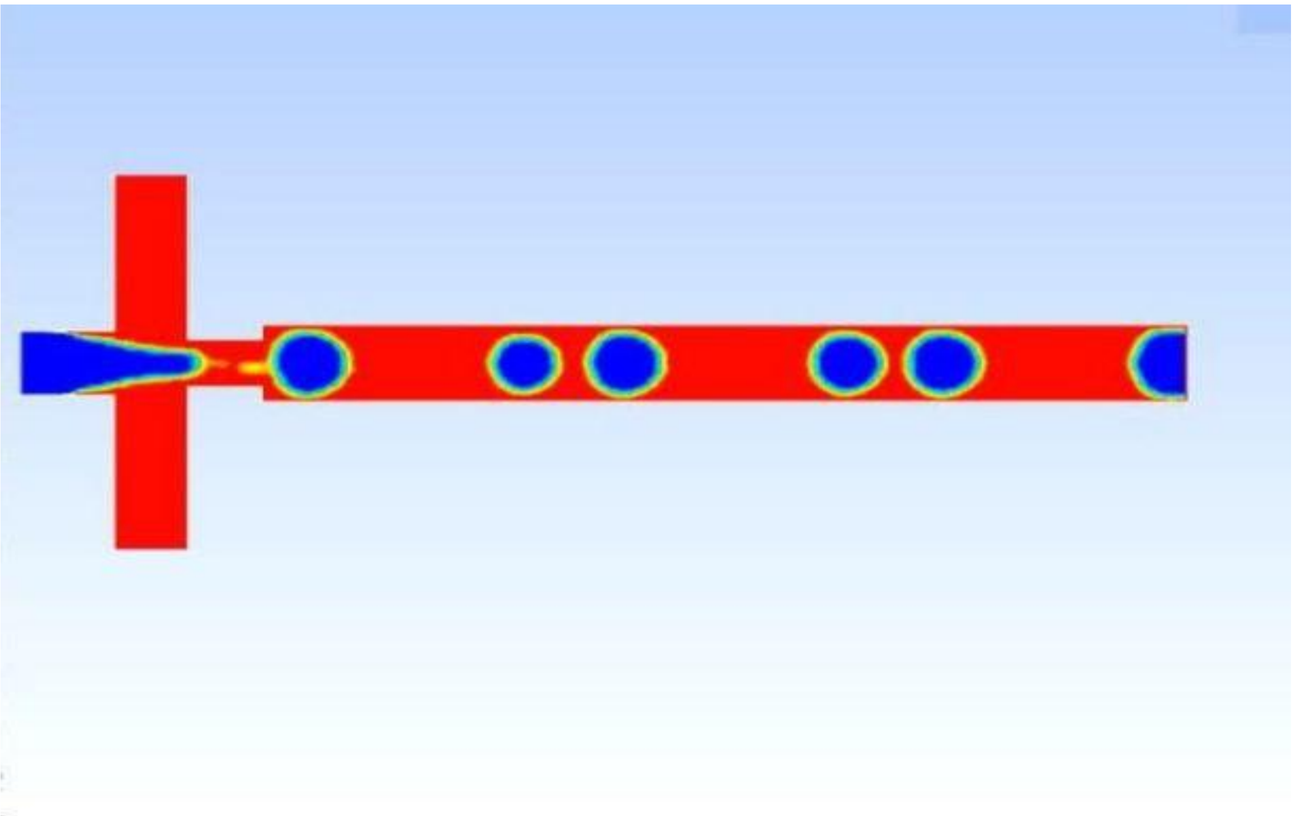


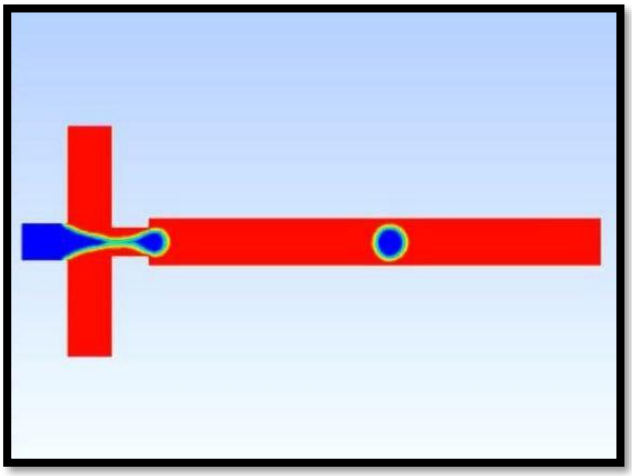
Fig 4. 2D microspheres produce in polymer emulsion during flow in microfluidic devices numerically by ansys software

TABLE 2
Model (A3) > Geometry

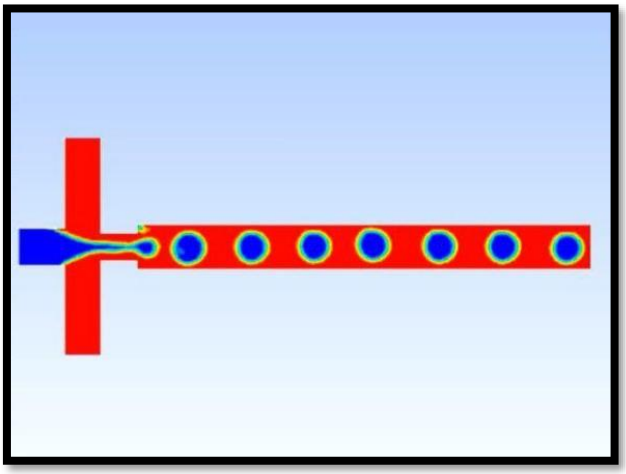
Object Name	*Geometry*
State	Fully Defined
Definition	
Source	D:\9Z\9z_files\dp0\FFF\DM\FFF.agdb
Type	DesignModeler
Length Unit	Micrometers
2D Behavior	Plane Stress
Bounding Box	
Length X	1260. µm
Length Y	480. µm
Properties	
Volume	1.512e+005 μm^3
Surface Area(approx.)	1.512e+005 μm^2
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	8955
Elements	8583
Mesh Metric	None

Table 2: Dimensions of the shape

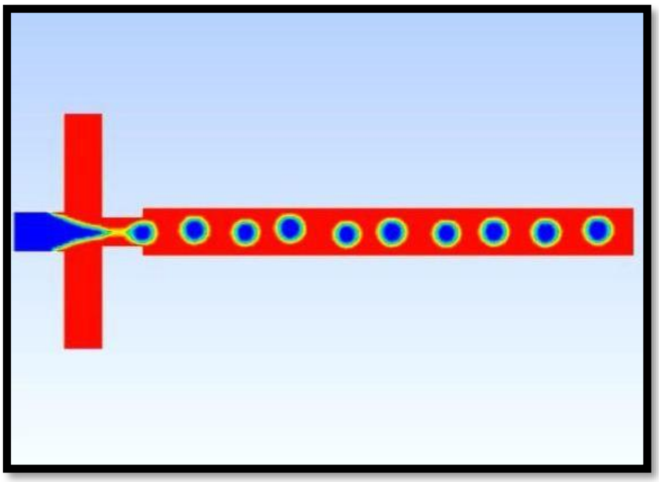
1. Velocity effect



(a)



(b)



(c)

Fig 5: Schematic diagram of microspheres in a microfluidic flow-focusing system with changing fluid velocity

(a) velocity of the water phase is(0.07 m/s) and oil phase is (0.015 m/s).

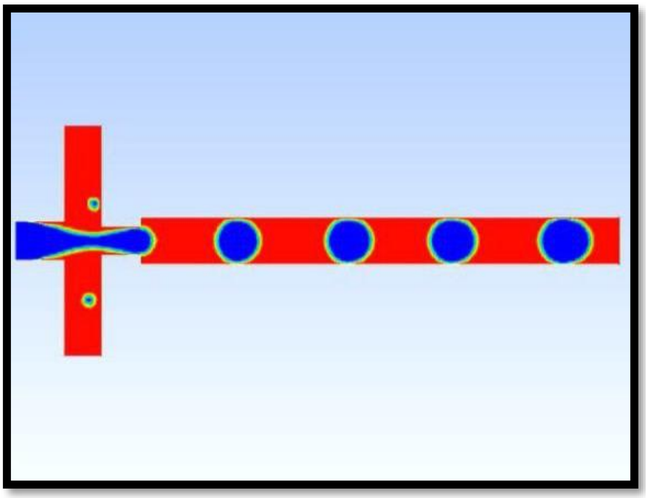
(b)velocity of the water phase is(0.07 m/s) and oil phase is (0.07 m/s).

(c) velocity of the water phase is(0.07 m/s) and oil phase is (0.05 m/s).

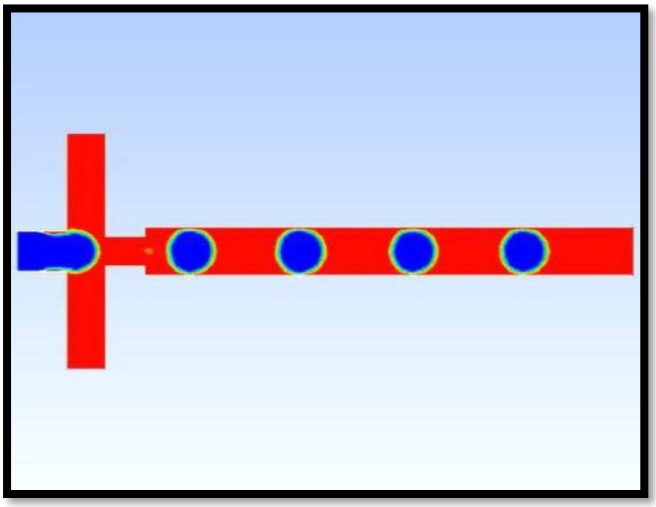
Fig. 5 Shows that the velocity increasing of oil phase from 0.015 to 0.05 m/s leads to the increasing of microspheres number from 1 to 3 per second . and decreasing of the size from (60-70) um to (45-30)um.

When changing fluid velocities, a significant impact on the size and productivity of the microspheres was observed. Figure (a) shows low productivity and a smaller size for the microspheres. Figure (b) Indicates high productivity and a larger volume for the microspheres. This proves the effect of velocity on the microspheres, in figure (c) It also high productivity and reduced particle size obtained. It also indicates that the size of microsphere reduce with the velocity increasing in other word the diameter of microsphere decreasing with ca number increasing

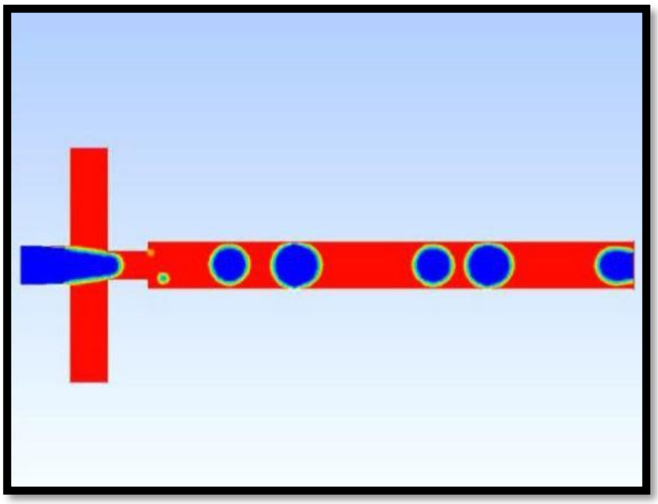
2. Density effect



(a)



(b)



(c)

Fig 6: contours of microspheres in a microfluidic flow-focusing system with changing oil phase density.

(a) density of the oil phase is(2940 kg/m3)

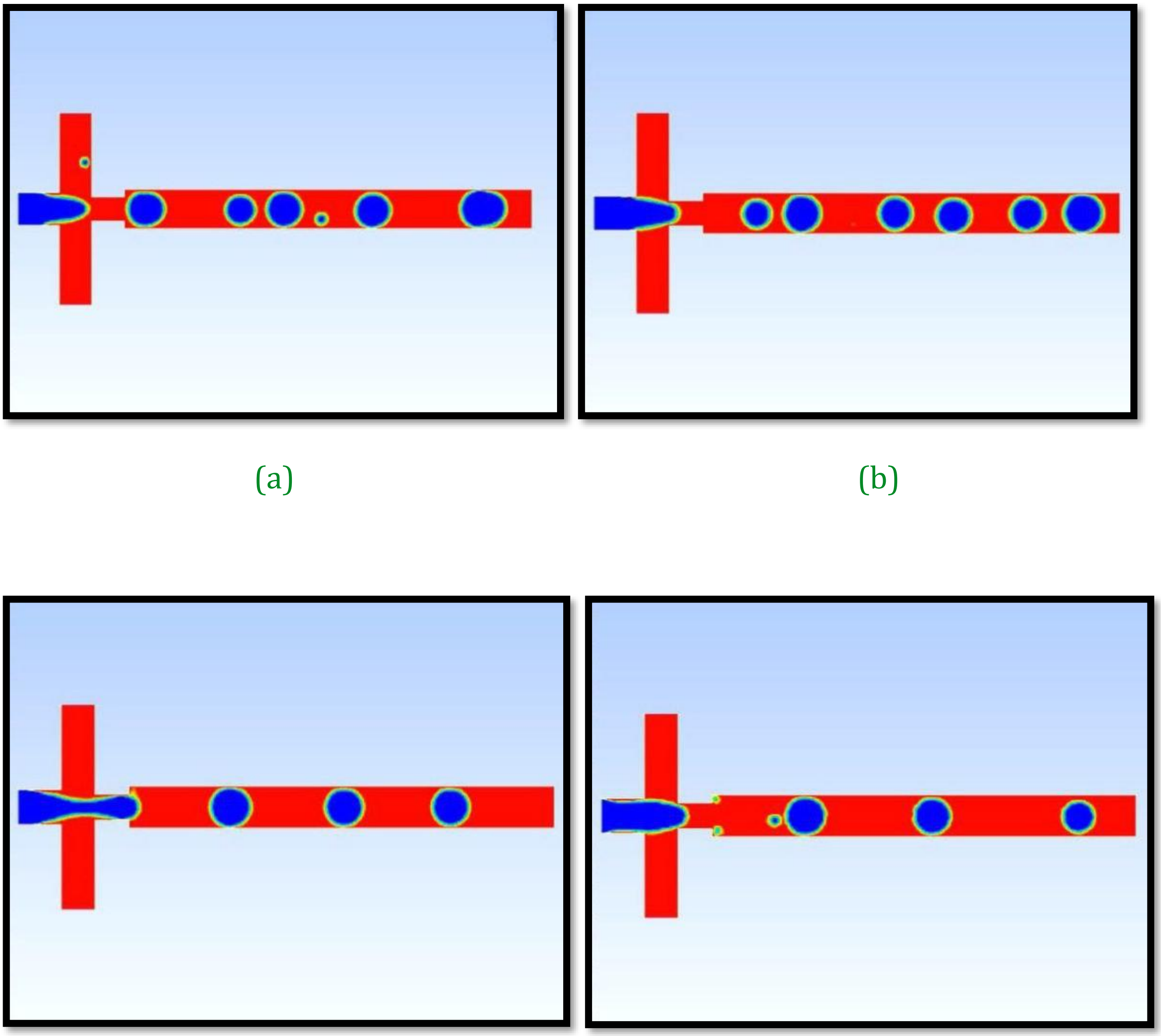
(b) density of the oil phase is(735 kg/m3)

(c) density of the oil phase is(367.5 kg/m3)

Fig. 6 shows that the microspheres became smaller with spherical shape and less number, due to the increasing in density,while microspheres transfer to spherical shape and broad distribution with the density decreasing.

Where it was observed that the size of the microspheres is less with the decrease in density, due to the decrease in the number of We, which led to a decrease in the diameter of the spheres, and that produce a regime of droplet of dripping type where it prevails in this case.The effect of density is minimal when it is a dripping regime, but the effect of density is clear when it is a jetting regime.

3. Viscosity effect



(a) (b)

(b) (d)

Fig 7: Schematic diagram of microspheres in a microfluidic flow-focusing system with changing fluid viscosity

(a) viscosity of the fluid 2 is(0.00606 kg/m-s)

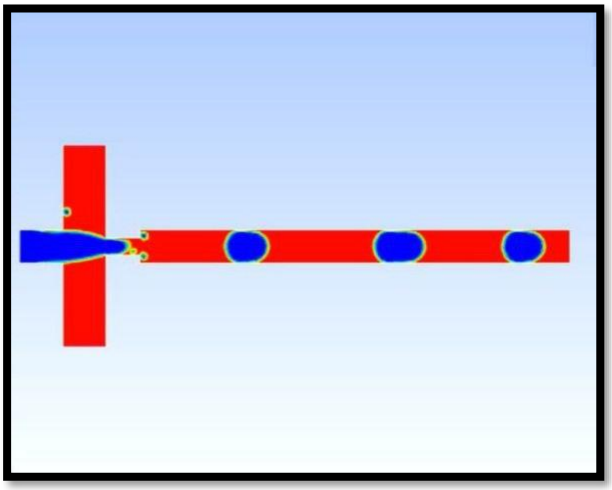
(b) viscosity of the fluid 2 is(0.01 kg/m-s)

(c) viscosity of the fluid 2 is(0.001515 kg/m-s)

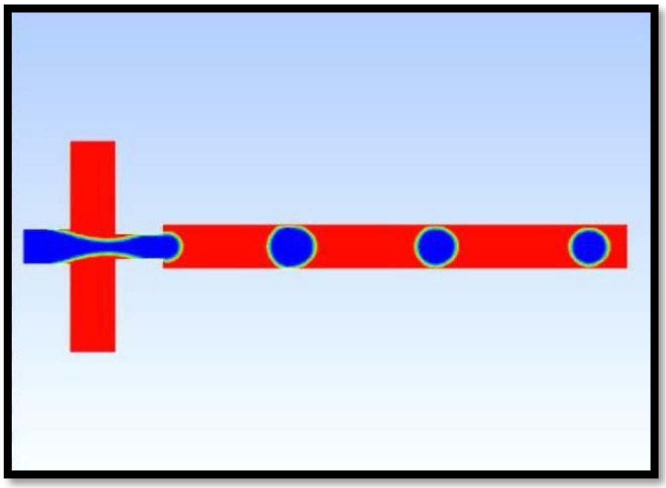
(d) viscosity of the fluid 2 is(0.0001 kg/m-s)

Fig. 7 indicates that the microspheres transfer from elliptical to spherical shape and from narrow to broad distribution due to the increasing in viscosity of oil phase. While the microspheres become spherical with the viscosity decreasing.The microspheres production in microfluidic during the emulsion flow decreasing with viscosity increasing this result is compatible with relation between microsphere diameter and capillary number.

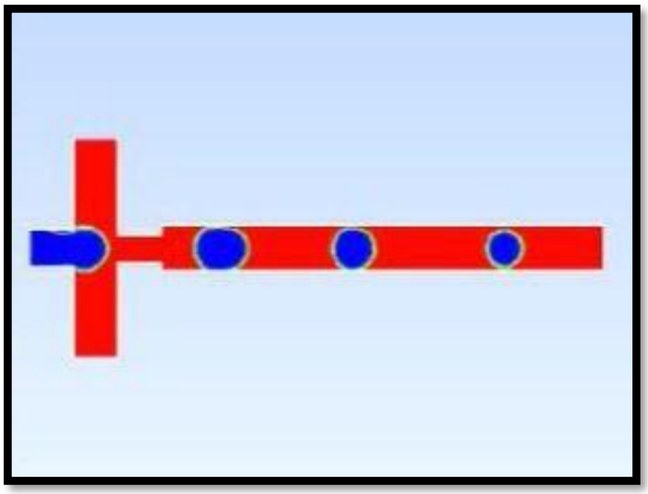
4. Geometry effact



(a)



(b)

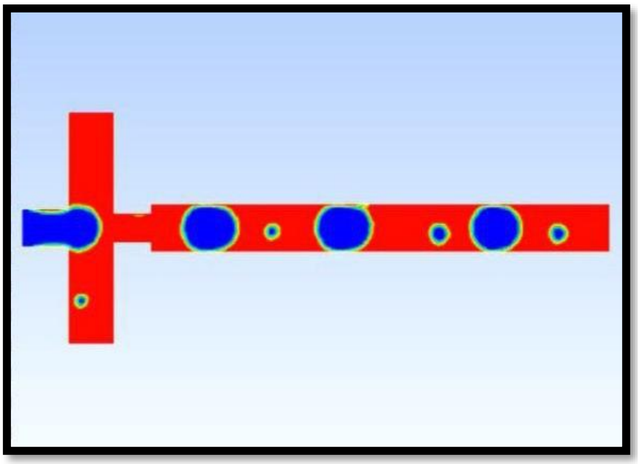


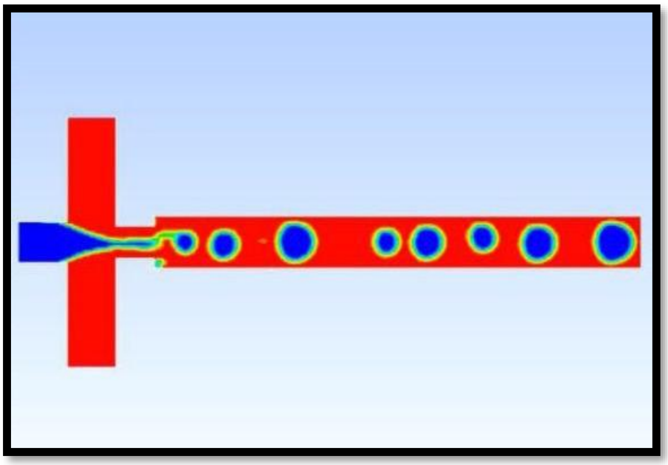
(c)

Fig 8:Schematic diagram of microspheres in a microfluidic flow-focusing system with changing channel diameter.

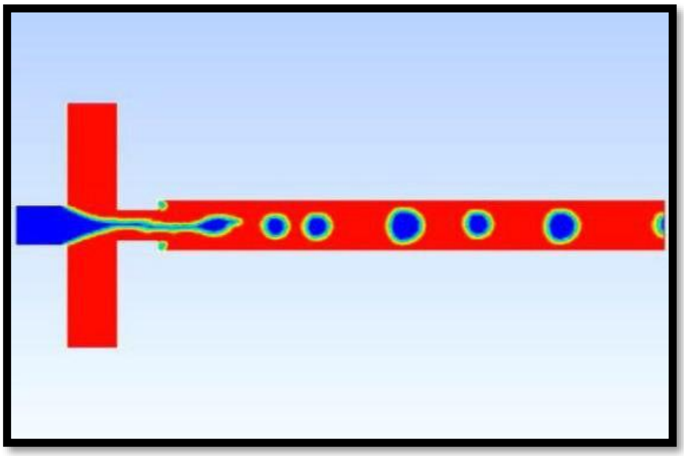
Fig. 8 Shows that atEach time the diameter of the canal was reduced by half, the size of the spheres was reduced each time.

5. surface tension effect





(a) (b)



(c)

Fig 9:Schematic diagram of microspheres in a microfluidic flow-focusing system with changingsurface tension.

. (a) Interfacial tension of the fluids I s(0.01 N/m)

(b) Interfacial tension of the fluids is(0.001 N/m)

(c) Interfacial tension of the fluids is(0.0005 N/m)

Fig. 9 Shows that the changing the interfacial tension from 0.01 N/m to 0.0005 reduced the size of the microspheres due to the increase in the Ca number, and this leads to a decrease in the diameter of the spheres and produce a broad distribution. With the reduction of Interfacial tension, the regime of droplet changed from dripping regime to jetting regime .

Chapter four

Conclusions

Conclusions:

1- Microfluidic systems have a tremendous potential for the production ofmicro particles that can be used for different therapeutic and diagnostic applications.

2- The production amount and droplet size were controlled by controlling the velocity and changing the density and viscosity.

3- The numerical simulation reduce time, cost, and effort to study the polymer behavior.

4- The microspheres type and regime can be controlled numerically which simplified manufacturing of microfluidic for different applications.

References:

[1] G. Cook, POLYMERS IN DRUG DELIVERY. Taylor & Francis Group, LLC, 2006

[2] K. K. Kim and D. W. Pack, "Microspheres for Drug Delivery," BioMEMS Biomed.Nanotechnol., pp. 19–50, 2006, doi: 10.1007/978-0-387-25842-3_2.

[3] X. Cao and M. S. Shoichet, "Delivering neuroactive molecules from biodegradablemicrospheres for application in central nervous system disorders," vol. 20, pp. 329–3391999,

[4] J. L. Cleland, E. T. Duenas, and A. Park, "Development of poly-(D,L-lactide-coglycolide(microsphere formulations containing recombinant human vascular endothelial growth factorto promote local angiogenesis," J. Control. Release, vol. 72, no. 1–3, pp. 13–24, 2001, doi/10.1016 :S0168-3659(01)00258-9.

[5] D. Jagadeesan, I. Nasimova, I. Gourevich, S. Starodubtsev, and E. Kumacheva, "Microgelsfor the encapsulation and stimulus-responsive release of molecules with distinct polarities",Macromol. Biosci., vol. 11, no. 7, pp. 889–896, 2011, doi: 10.1002/mabi.201100045.

[6] L. Mu and S. S. Feng, "A novel controlled release formulation for the anticancer drugpaclitaxel (Taxol): PLGA nanoparticles containing vitamin E TPGS," J Control Release, vol,86 .no. 1, pp. 33–48, 2003, doi: 10.1016/S0168-3659(02)00320-6.

[7] J. H. Xu, S. W. Li, C. Tostado, W. J. Lan, and G. S. Luo, "Preparation of monodispersedchitosan microspheres and in situ encapsulation of BSA in a co-axial microfluidic device",pp. 243–249, 2009, doi: 10.1007/s10544-008-9230-3

[8] C. M. B. Ho, S. H. Ng, K. H. H. Li, and Y. J. Yoon, "3D printed microfluidics for biologicalapplications," Lab Chip, vol. 15, no. 18, pp. 3627–3637, 2015, doi: 10.1039/c5lc00685f .

[9] T. M. Squires and S. R. Quake, "Microfluidics: Fluid physics at the nanoliter scale," Rev .Mod. Phys., vol. 77, no. 3, pp. 977–1026, 2005, doi: 10.1103/RevModPhys.77.977 .

[10] P. Garstecki, I. Gitlin, W. Diluzio, G. M. Whitesides, E. Kumacheva, and H. A. Stone , Formation of monodisperse bubbles in a microfluidic flow-focusing device," Appl. Phys .Lett., vol. 85, no. 13, pp. 2649–2651, 2004, doi: 10.1063/1.1796526 .

[11] T. Ward, M. Faivre, M. Abkarian, and H. A. Stone, "Microfluidic flow focusing: Drop sizeand scaling in pressure versus flow-rate-driven pumping," Electrophoresis, vol. 26, no. 19 ,pp. 3716–3724, 2005, doi: 10.1002/elps.200500173 .

[12] C. Y. Lee, Y. H. Lin, and G. Bin Lee, “A droplet-based microfluidic system capable ofdroplet formation and manipulation,” Microfluid. Nanofluidics, vol. 6, no. 5, pp. 599–610,2009doi: 10.1007/s10404-008-0340-2 .

[13] D. J. Beebe, G. A. Mensing, and G. M. Walker, “Physics and Applications of Microfluidics inBiology,” Annu. Rev. Biomed. Eng., vol. 4, no. 1, pp. 261–286, 2002, doi10.1146 :/annurev.bioeng.4.112601.125916.

[14] A. Ashish Saha and S. K. Mitra, “Effect of dynamic contact angle in a volume of fluid (VOF)model for a microfluidic capillary flow,” J. Colloid Interface Sci., vol. 339, no. 2, pp. 461 –480, 2009, doi: 10.1016/j.jcis.2009.07.071.Anna SL, Mayer HC (2006) Microscale tipstreaming in a microfluidic flow focusing device. Phys Fluids 18:121512

[15] Anna SL, Bontoux N, Stone HA (2003) Formation of dispersions using “flow focusing” in microchannels. Appl Phys Lett 82:364–366 Bai YP et al (2010) A double droplet trap system for studying mass transport across a droplet-droplet interface. Lab Chip 10:1281–1285

[16] Finehout E, Tian W-C (2009) Microfluidics for biological applications vol 1. Aufl., vol Book, Whole. Springer, Boston Fu TT, Wu YN, Ma YG, Li HZ (2012) Droplet formation and breakup dynamics in microfluidic flow-focusing devices: from dripping to jetting.

[17]Widder KJ, Morris RM, Poore G, Howard DP, Senyei AE (1981) Tumor remission in Yoshida sarcoma-bearing rats by selective targeting of magnetic albumin microspheres containing doxoru- bicin

[18] C. Y. Lee, Y. H. Lin, and G. Bin Lee, “A droplet-based microfluidic system capable of droplet formation and manipulation,” Microfluid. Nanofluidics, vol. 6, no. 5, pp. 599–610, 2009, doi: 10.1007/s10404-008-0340-2.

[19] D. J. Beebe, G. A. Mensing, and G. M. Walker, “Physics and Applications of Microfluidics in Biology,” Annu. Rev. Biomed. Eng., vol. 4, no. 1, pp. 261–286, 2002, doi: 10.1146/annurev.bioeng.4.112601.125916.

[20] A. Ashish Saha and S. K. Mitra, “Effect of dynamic contact angle in a volume of fluid (VOF) model for a microfluidic capillary flow,” J. Colloid Interface Sci., vol. 339, no. 2, pp. 461– 480, 2009, doi: 10.1016/j.jcis.2009.07.071.

[21] B. E. RAPP, Microfluidics: modeling, mechanics, and mathematics. Elsevier Inc., 2017.

[22] M. Al-Atabi, S. B. Chin, X. Y. Luo, and S. Al-Zuhair, "Pressure Drop in Laminar and Turbulent Flows in Circular Pipe with Baffles - An Experimental and Analytical Study," Int. J. Fluid Mech. Res., vol. 33, no. 4, pp. 303–319, 2006, doi: 10.1615/interjfluidmechres.v33.i4.10.

[23]Haznedar S, Dortue B. Preparation and in vitro evaluation of eudragit microspheres containing acetazolamide. Int J of Pharm, 2004, 269: 131–140.

[24]. Hora MS, Rana RK, Nunberg JH, Tice TR, Gilley RM and Hudson ME. Release of human serum albumin from PLGA microspheres. Pharm Res, 1990, 7:1190-1194.

]25]. Ishida, M, Nambu N, Nagai T. Highly viscous gel ointment containing carbapol for application to the oral mucosa. Chem. pharm Bull. 1983, 31:4561.

[26]. Jackson, LS and Lee K. Microencapsulation and the food industry. Lebennsmittel-Wissenschaft Techonologie. Ret on Cont Rel, 1991, 5: 199-205.

[27]. Jegat C, Taverdet J L. Stirring speed influence study on microencapsulation process and the drug release from microcapsules. Polymer Bulletin, 2000, 44: 345–351

[28]. Jain N K., Controlled and Novel drug delivery. CBS Publisher, 1997, pp 236-237.

[29]. Jian You, Fu-de Cui, Xu Han, Yongsheng Wang, Lei Yang, Ying-Wei Yu, Qing-po. Literature of Biointerfaces, 2006, pp 35-41

[30]. James S. Encylopedia of PharmaceuticalTechonology, 2005, 3: 1325-1333. Khawla A, Abu izza, Lucila Garcia-Contreras, Robert Lu D. Selection of better methed for the preparationof microspheres by applyinghierarchy process. J. Pharm Sci 1996, 85:144-149.

[31]. Khawla A, Abu izza, Lucila Garcia-Contreras, Robert Lu D. Selection of better methed for the preparation of microspheres by applying hierarchy process. J. Pharm Sci, 1996 , 85:572-575