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Nonisothermal CFD simulation of electrocoagulation reactor

A Thesis

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Abstract

EC(Electrocoagulation) consider one of most important method to purify the wastewater, due to economist ,simple to build, run , maintain and low energy consumed. This research is dealing with non-isothermal EC process using computational fluid dynamic (CFD) to simulate the process the EC reactor consist of two parts ,anode and cathode ,the anode is rotating parts and the rest of reactor is cathode. The reactor volume is 800Cm^3 the reactor height is 15 Cm and the radius is 5 Cm .The software is COMSOL multi-physics 5.5 is depended to solve differential equations, four kind of differential equations have been solved to reach to results, mass transfer of dilute spices, heat transfer, secondary currant density and laminar flow. The research take the current and applied voltage in steady state and the concentration as well as the temperature in time dependent Taking six different time for each case of parameters ,0,20,40,60,80 and 100 min. to compare among them ,then conclude the result to study them. The pollutant is lead with 1 mol/m^3 initial concentration, different parameters have been studied, one of the most effecting parameters is applied voltage, with increasing applied voltage the current density increased and the temperature of the process, then leading to improve the lead removal The applied voltages that used in this research are 1.5,3,6 and 10 V .The rotational anode speed improve the lead removal within limits which is in this case 50 rpm, more than this limit the lead removal efficiency become negative the rotational speeds which depended are 0,10,50 and 100 rpm .HRT(Hydraulic retention time) has been studied ,the results show that the influence of it is very slightly compares with other variables because the reaction is very fast ,HRT has been taken (10,20,30 and 40 min) the result shows that the HRT doesn't effect on coagulants and lead concentration while the temperature increase with increasing the HRT .Then the isothermal process studied ,to compare the two situations and find out the result in both cases .The CMOSOL graphics and charts were used to clarify the results. The results shows the time needed to remove entire leads decreases with applied voltages, current ,rotational speed till 50 rpm .The research assumed that ,the work scope in the 3D,laminar flow ,nonisothermal process, Newtonian fluid ,constant pH.

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Nomenclature

<u>Symbol</u>	<u>Description</u>	<u>Unit</u>
W	The amount of anode material dissolved	g
I	Current	A
t	Electrolysis time	min.
M	Specific molecular weight of the electrode	g/mol
Z	Electrons No. direct react	(-)
F	Faraday's constant	96485C/mol
P	Pressure	Pa
F	Volume force vector	N/m ³
u	Mean velocity	m/s
N_i	Flux of the chemical species	mol/m ² .s
D_i	Diffusion coefficient	m ² /s
C_i	Average concentration	mol/m ³
$u_{m,i}$	Mobility of species	m ² /V.s
q_e	Adsorbed molecules / Adsorbent at equilibrium	mg/g
C_e	Concentration of equilibrium adsorbent	mol/m ³
q_{max}	Capacity of adsorbed molecules / Metal cations	mg/g
V	Solution volume	m ³
K_L	Constant of Langmuir adsorption isotherm	m ³ /mol

i	Electrolyte current density	A/m^2
E_{cell}	Cell voltage	V
V_R	Reactor volume	m^3
Q	Flow rate	m^3/s

Symbols

<u>Greek letters</u>	<u>Description</u>	<u>Unit</u>
ρ	Density	kg/m^3
μ	Dynamic viscosity	Pa.s
φ	Electric potential	V
σ_l	Electrolyte conductivity	S/m
φ_l	Electrolyte potential	V
ε	Current efficiency	(-)
ε_M	Efficiency of hydro-pollutant-aluminum formation	(-)
w	Angular velocity	rpm

Abbreviations

AEC	Alternating Electrocoagulation Current
ALR	Airlift Reactor
ANN	Artificial Neural Network
ANOVA	Analysis Of Variance
BBD	Box-Behnken Design

BOD	Biochemical Oxygen Demand
BYEs	Bakers Yeast Effluents
CCD	Center Composite Design
CFD	Computational Fluid Dynamic
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
DOP	D-Optimal
EC	Electrocoagulation
FD	Factorial Design
HRT	Hydraulic Retention Time
KA	K-Acid
NOM	Natural Organic Matter
RSM	Response Surface Method
SE	Supporting Electrolyte
SEM	Scanning Electron Microscopy
SS	Suspended Solids
STR	Stirred Tank Reactor
TOC	Total Organic Carbon
VOK	Variable Order Kinetic

Chapter One: Introduction

1-1 Background .

The first time was introduced to treat water by EC was in 1889 in the UK which is mean provide the metallic hydroxide floccs by electro solution of electrodes, later on in the USA the Aluminum and iron electrodes were used in 1909. At that time ,because of high capital required and the expensive power supply as well as providing the chemical coagulant as alternative ways ,these reason prevent the EC from spread wildly around the world .After that in the 1970s and 1980s the Russian researchers studied the EC in the water treatment .

These days EC is consider as good and reliable way to treat a wide range on pollutants after getting the EC the focus and study it then get improved, these pollutants are phenolic waste, arsenic, aqueous suspensions of ultrafine particles , nutrients, chemical and mechanical polishing wastes, suspended particles, organic matter from landfill leachate, polymeric waste, fluoride, textile dyes, oil wastes, foodstuffs and heavy metals.

This flexibility to remove a wide range of pollutants make efforts focus to develop this technology, **Dura 2013.**

1-2 Principles Of Electrocoagulation.

EC technology is simply base on the principle of provide the ions to react with the pollutants to remove them, mainly used to treat the waste and drinking water .It consist of an electrochemical cell with both electrodes (anode and cathode) put it into t or electrolyte associated together to the electrical source the chemical reaction e in the cell are oxidation and reduction which occurs in the electrodes /electrolyte interface ,the oxidation reaction is happen in the anode while the reduction is in the cathode (sacrificial electrode which corrode to release coagulant

cation) in most cases used iron or aluminum. At the same time EC is releasing electrolytic gas mainly H_2 at the cathode.

The current flow via the EC cell by moving the electrons by the solution electrolyte through transfer the charged species. The electrolyte high conductivity help to reduce the resistance for the power consentaneously the electrical consumption,**Dura2013**.

The cations created due to anode hydrolysis to hydroxides , poly hydroxides , and poly hydroxyl metallic compounds which eventually cause the coagulation . They can lessen the net surface charge of colloidal particles that are in suspension because of the decrease of the terrible capability of the charges twofold layer. Therefore, the shocking powers among the colloidal particles lessening and this make the particles adequately close with the goal that the van der-Waals forces prevail and agglomeration of the particles happens. The electrocoagulation cycle comprise of three progressive stages .

The main stage contains development of coagulants from the surficial anode by oxidation of the conciliatory. Then the moving of the debasements and particulate suspension happens, lastly the total of the undermined stages to shape flocs happens. The destabilization of the suspension includes the event of the coagulation cycle and can be achieved by a few mechanism. On the opposite side, the development of flocs is dictated by flocculation models. It is important that in electrocoagulation the cycles of coagulation and flocculation happen at same time and it is beyond the realm of imagination to expect to recognize the two steps as in chemical coagulation **Figure(1.1)**. Without a doubt, when metal salts are utilized in water treatment equipment's, the two phases, coagulation and flocculation, are actually isolated or separated based on the time needed for every one of the cycles, **Bennajahetal2010**.

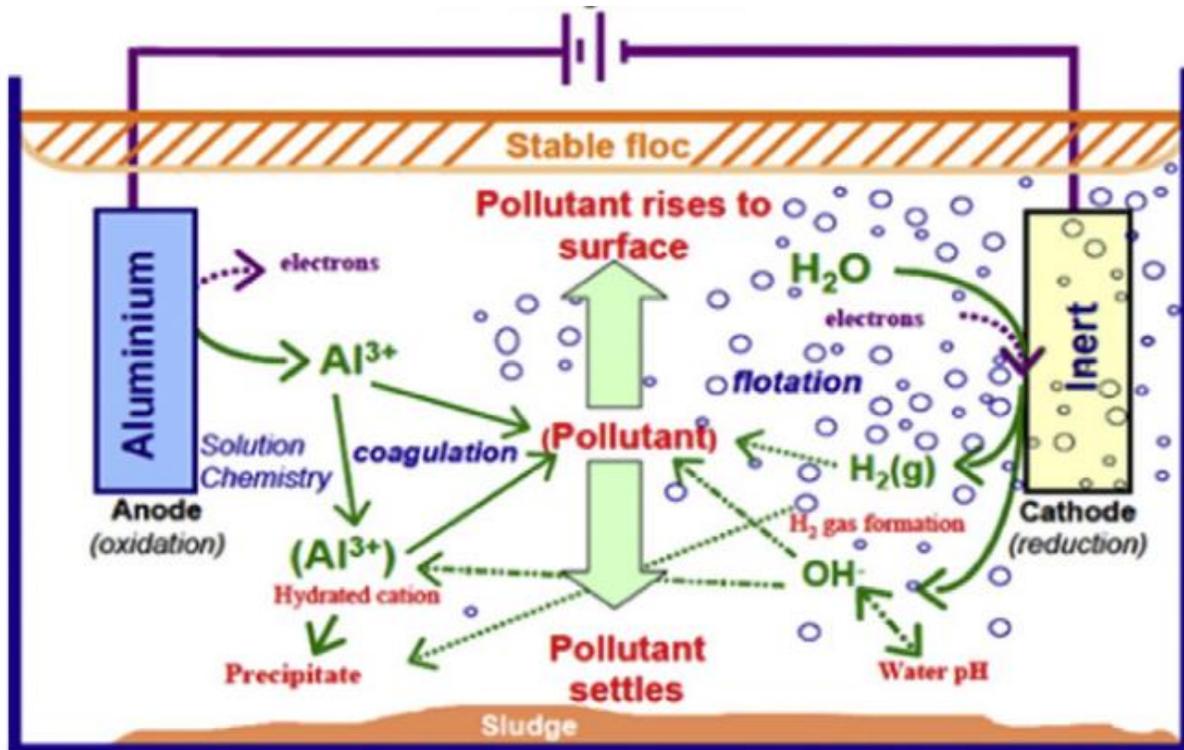


FIGURE (1.1). electrocoagulation cell Hakizaman et al.(2017)

1-3 Advantages And Disadvantages Of Electrocoagulation.

In this section the advantages and disadvantage are going to review briefly .

There are many advantages the following are some of them:

- 1-The EC cell is easy to operate.
- 2-Low cost relatively comparison with other technique.
- 3- Less maintenance than others due to has no moving parts.
- 4- It can be used in remote areas even there is no electricity, the power can be provided by solar system.
- 5- It is consider option no.1 for the small and localize treatment .
- 6- In the EC process there is no need to use the chemical coagulant consequently the side pollutants are very little.

7-The flocs are larger, less bound water, don't effected by acid and its stability is high ,for all these reasons it's easy to be differentiated by using filtration .

8-In the electrocoagulation process the small colloidal spices can be removed as a result of electrical field which make them move faster so facilitating their Agglomeration.

9-Bubbles generation is another advantage ,they can bring the flocs to the top where they easily can be removed.

The following points are the disadvantages:

- 1- The power cost which consider one of the constrain.
- 2- Passive film or oxide on the electrode surfaces which make the cell less efficient.
- 3- The high conductivity of the solution can cause gelatinous hydroxide may tend to solubilize , **Dura (2013)**.
- 4-

1-4 Elements Affecting Electrocoagulation

1-4-1 Anode and cathode martial

The anode and cathode materials are chosen depending on the containment that need to be eliminate and their chemical properties which they responsible to the electrochemical reaction in the EC cell. The most materials are being used are aluminum and iron , aluminum gives the Al^{+3} ions ,while the iron gives either Fe^{+2} or Fe^{+3} .The preferable material in general is the aluminum in efficiency regard in spite of it is cost more than iron.

In case of present the calcium or magnesium ions, it is recommended to use the inert material as cathode such as stainless steel, **Ahmed et al.(2010)**.

1-4-2 pH

One of the factors that affecting on the electrochemical reaction is the pH. Each pollutant to be removed has optimum pH base on that the change from this point the removal of this material will be decreased. The PH depending on the reaction of the cell and the ions that formation as result of the reaction ,such as OH^- and Al^+ ,**Nwabanne et al.(2013)**.

1-4-3 Temperature

Ahmed et al(2016) studied the Electrocoagulation using a rotated anode including the influence of temperature they found out that the elimination of pollutants that need to be removed and color become better when the temperature increased (95%,96.2% for COD, 93%,94.75% for TSS, and 95%, 97% for the dye). The influence of temperature increasing in Al^{+3} to $\text{Al}(\text{OH})_3$ and increasing in Al^{+3} diffusively according to the Stokes- Einstein's ,So the mass transfer is increasing from the electrode surface to the solution bulk. **El-Ashtoukhy et al.(2013)** found that increasing in temperature greater than 40°C the solubility of $\text{Al}(\text{OH})_3$ increase that cause losing of coagulant ,in general the advantage gains are greater than the disadvantage for temperature .

1-4-4 Current Density

Current density one of the most important parameters that affecting the efficiency of the EC as it cause increase or decrease in dissolution of the anode ,which affecting on the determines of coagulant rate ,bubble production rate, size and grout of flocs .The increasing in current density lead to increasing in dissolution in anode which cause raising in metal hydroxide flocs ,that eventually lead to increasing in the EC efficiency .The increasing in current density above the

ideal limits doesn't increasing elimination of the pollutants as a result of available sufficient ions on coagulant , **Nasrullah et al.(2014)**.

1-4-5 Voltage

Orathai Chavalparit1 et al (2009) tested the applied voltage between (10 - 30 V_g) that's equal to the current density range 6.7–20.8 mA/cm² with regardless the effect of the pH and the time they figure out that significant increasing pollutants elimination by increasing in the applied voltage base on Faraday's law. The increasing in the current density is directly proportional to the coagulant and the anodic ions in certain time .As a result of increasing the current density or applied voltage ,the aluminum hydroxide ions increase, as aside affect the pH raise.

1.5 The study objective

The objective of this research is to study the different parameters effect on lead removal by the EC process ,these parameters are applied voltage ,HRT, rotational speed and temperature .The applied voltage is taken 1.5,3,6 and 10V.The rotational speed is taken 0,10,30,50 and 100rpm.The HRT is taken 10,20,30 and 40 min.

Chapter Two: literature review

2.1: Introduction

Many studies have discussed the EC and the factors that affecting on its performance, including pH, Temperature, electrode material, the distance between electrodes, current density, voltage, the pollutant concentration etc., some of them depending on the experiments while the others on the simulation studies.

The following is some of these studies :the purpose, the assumptions and the conclusion for each research .

2.2: Experimental Studies

Forat Yasir et al.(2018) studied lead removal wastewater by using EC process. That adsorption process is more efficient for range of current density value by using EC, this process under pseudo-first order kinetics and intra-particle diffusion studied graphically, by using Langmuir and Freundlich . The result shows that the adsorption process of lead was spontaneous and endothermic in nature.

Aditya Choudhary(2017). studied performance evaluation of non-rotating and rotating anode reactor in electro coagulation process. In this study the comparison between the rotation and non-rotation electrode ,it's found that the rotational reactor is more effective than non-rotational by 10-15 % to remove COD.It also found that the energy consumption is decreased by 17-58 % in rotational reactor .For the current density and time ,it's found that the rotational reactor better efficiency .

Afnan et al (2017) had studied the continuous EC process to treat the wastewater, they used reactor with rotating anode from Al , The best operating conditions for lead ions removal for the aqueous solution were found to be at HRT

35 and 45 min, applied voltage 10V, rotating speed of electrode 100 rpm ,distance between electrode 2.3 cm and effective area of electrode 65cm^2

Ahmed et al.(2016) studied EC utilizing a rotational anode . They use a relatively new cell of EC which higher efficient than the old design when remove the textile in wastewater ,the removal efficient is higher with low current density especially 4mA cm^{-2} during the first 10 minutes and 150 rpm of rotational speed and 1cm inter electrode distance .No importance to fix the PH or the temperature ,no need to add the chemical ((NaCl or Na₂SO₄),the economic issue is affected by electrode and energy consumption ,by increasing the current density the electrodes and energy consumptions increase ,the best electrodes and energy consumption were 0.038 Kg/cm^3 and 4.66 Kwh/m^3 respectively which minimize the coast by $0.44\text{ us\$/m}^3$.

Sandeep et al.(2016) studied treatment of Wastewater by Electro coagulation. They approve that the EC is a good alternative technique to treat the water and remove the pollutants ,it's good to remove the color and chemical oxygen demand COD and biochemical oxygen demand BOD and other impurities from the water .

Rawaa et al (2016) has studied batch EC ,they found out that the lead removal is decrease in high rotating speed ,the lead removal is decrease with increasing the electrodes distance and the applied voltage ingance the lead removal.

Kamaraj et al.(2015) studied elimination of pollutants from waterly solutions by EC isotherm. That the best operation conditions to achieve 99.3 % of heavy metal removal from drinking water are current density is 0.8 A/dm^2 and at pH is 7.0 when using magnesium as anode and stainless steel as cathode, using magnesium as anode and stainless steel as cathode ,the EC was demonstrated by utilizing adsorption isotherm viz., Langmuir and Freundlich. The lead adsorption was best fitted by the Langmuir adsorption isotherm, and the outcomes were in acceptable concurrence with the trial information. The thermodynamic boundaries

Enthalpy ,Entropy and Gibbs energy had been studied .When increasing the T from 303k to 343 k the enthalpy will increase that mean the process is endothermic .The increasing in entropy refer to increasing randomly in leads adsorption by magnesium hydroxide.

Attour et al.(2014) studied impact of working boundaries on pollutants expulsion from H₂O by EC utilizing Al electrodes. The removal of phosphate by aluminum electrodes EC optimum by 5mm distance between electrodes and the source pH is 3 and conductivity is 3.2 ms in the batch reactor .In this study the phosphate removal and pH had against time had been studied ,they reach to the efficiency of removal is depending on the electrical charge (time of treatment and current densities are linked together .When the pH is low the AlPO₄ by participation while the Al(OH)₃ predominate when pH increase .The changing in pH because the OH⁻ generated in cathode .The phosphate removal was enhanced by temperature.

Edris bazrafshan et al.(2014) studied EC measure utilizing Iron and Aluminum as electrodes for Fluoride expulsion from fluid .In this study the Al and Fe used as electrodes to remove the fluoride from the aqueous solution .The conductivity of solution ,pH and time was investigated .The time range was 0-60 min ,voltage 40 V .

Saber E. Mansour et al. (2013) studied removal of Cadmium pollutants in drinking water using alternating current electrocoagulation technique. The optimum conditions where 98.2 of AC removal are current density of 0.04gA/m , 70gV and pH of 8.9 using 2 aluminum amalgam as anode and cathode . The adsorption of cadmium on aluminum hydroxide affirms better relevance of pseudo-second-order rate condition as obvious from relapse coefficient.

A.H. El-Shazly et al.(2013) studied kinetics and performance of phosphate removal from hot industrial effluents using a continuous flow Electrocoagulation

reactor. The phosphate ions to be removed from wastewater using forced circulation flow. first order rate equation and further shows that the process activation energy is about 5.004 kCal/mol. The efficiency increased when increasing the circulation of solution ,decrease the initial phosphate concentration and increase the temperature up to 60 Celsius ,however increase the T above these limit could be decrease the efficiency .

Armando et al.(2013) studied the significance of current circulation and cell hydrodynamic investigation for the plan of electrocoagulation reactors. The effect of the hydrodynamic and current distribution , in the efficiency of EC in this study they found out the difference in clots formation of hydrodynamic and removal of slug ,regarding the current distribution they figure out its very important to arrange the electrodes.

Subramanyan Vasudevan et al (2011) studied the Al–Zn–In-amalgam as anode material for the removal of chromium from humane used H₂O by EC. The outcomes showed that the advanced expulsion proficiency of 98.2% was accomplished at an ideal current density of 0.2 Agdm⁻² and a pH of 7.0 utilizing aluminum alloy as anode and galvanize iron as cathode. In the reactor the response between aluminum hydroxide and chromium which consider as poisons Langmuir adsorption isotherm was found to fit the balance information for chromium adsorption. The adsorption interaction follows the first order kinetic. Temperature And heat investigation prove that the adsorption was endothermic and unconstrained.

Mehmet Kobya et al. (2011) studied treatment of consumable water containing low convergence of arsenic with electrocoagulation. Batch process had been considered with various changeable parameters like ,current density ,pH ,time and initial concentration .At the optimum condition the arsenic concentration had been decreased to less than 10 micro g/L when using Al and Fe as electrodes The

highest removal efficiencies of arsenic at MPS mode were 99.3% for Fe at pH 6.5 and 98.9% for Al electrode at pH 7 respectively and lowest cost .

Reza Katal et al.(2011) studied the efficiency of EC when using different kind of anode and cathode like Fe and Al. The best result can be obtained by applying the parameters pH 5-7, the EC is more effective at lower temperature, by heating the solution from 20-60 C that lead to reduce efficiency by 20%, when using aluminum electrodes, they found out that the EC a technique to reduction the color ,phenol and COD in paper mill wastewater ,the influence of variable conditions had been concluded .The Al was used as sacrificial anode .The fast removal of pollutants at 30 min when with low electrode consumption when using 70 mA cm^{-2} .

Lazare Etiégni et al.(2010) had studied treatment of wastewater by electrocoagulation . In this study they found that the EC is good alternative method to treat wastewater however the replacement of electrode and the power cost are the constrain in spite of new electrodes had been set polypyrrole (PPy) and boron doped diamond (BDD).Some supporting material are available to electrolyte like wood ash and leachates are cheap and make the process more effective .

Chaloempan Petsriprasit et al (2010) studied use of the electrocoagulation method for elimination the substantial metals containing wastewater from the pickling system of a billet plant. In this study the researchers had achieved, that the EC is the most effective technique at least in the lab, however there are many parameters that affecting the process efficiency like the pH ,current density ,the initial concentration and time. In billet plant pickling process wastewater, the optimum conditions were current density of 98 A/m^2 , an initial wastewater pH of 5 and 30 min electrolysis time as batch process where the lead had been removed by 99% with reducing 50% of energy consumption 3 KWh/M^3 . For the consistent test, the treatment framework arrived at its consistent state condition inside 120g

min and ideal conditions were not that distinctive being an ebb and flow thickness of 98gA/m^2 , a feed pace of wastewater of 55gml/min and an underlying pH of 3. The cost didn't estimated because the study had been in lab.

BalaSubramanyana et al.(2009) found that the efficiency removal reached to 98.2% by using current density 0.2 Agdm^{-2} and a pH of 7.0 when they used Al compound as anode and electrifies iron as cathode to treat the waste water.

N. Balasubramanian(2009) studied removal of arsenic from aqueous solution using electrocoagulation. In this study shows that the EC is promising remediation to remove the pollutants from the material. Its show that the arsenic removal by absorption or co-precipitate with Iron(III) hydroxide. By increasing the current density from 0.5 to 1.5 A dm^{-2} increasing the arsenic removal, however above this current there is no significant extra removal of arsenic. More than 98% of arsenic had been removal in this study. The electrocoagulation has been modeled using adsorption isotherm models and observed Langmuir isotherm model match satisfactorily with the experimental observations.

Mohammad et al.(2004) studied essentials, present and future viewpoints of electrocoagulation. The EC fundamental reach to that the up-flow is better than the horizontal flow, using sonic field and agitation and hybrid EC-electro flotation is enhance the EC process efficiency. This technique to treat the water still need to be studied and developed as its contains many physical and chemical phenomena.

Ibtehal et al.(1997) studied lead removal from industrial wastewater by electrocoagulation process. They found the clarification after the EC is high efficient comparison with other technique, where the efficiency increase with increasing the pH till 10 and with increasing current density with best value is 1.2 mA/cm^2 and the lead had been completely removed with end of process which take 120 min ($30, 70$ and 120 mg/l). The anode was from Al and the cathode from stainless steel.

2.3 Theoretical Studies:

There are many kind of study ,the following are the summary about these types:

Andrii Safonyk et al.(2019) studied the EC by developing a mathematical model depending on the heat and mass transfer equation .The solution based on the asymptotic approximation of boundary value problem found that the iron concentration and heat distribution depend on the current applied .The method of the solution can be used to analysis the influence of heat and mass transfer and kinetics of the reaction ,the experimental and theoretical studied to optimum the condition in the EC .

Andrii Safonyk et al .(2019) studied the simulating and robotization of the electrocoagulation cycle in water treatment, SCADA-system WinCC Flexible has been used to simulate the EC ,the factors that affecting on the process ,current ,voltage geometry and temperature ,he found that The automation control system with P-regulator can conserve up to 21.4% of power expenses.

Abdulaziz Alghamdie et al.(2019) studied the electrocoagulation Process, a mechanistic review at the dawn of its modeling, they closed to the accompanying ,the logical had practical experience in the EC cycle is close to recommend exact/hypothetical models to introduce the EC innovation as a suitable green interaction. In any case, more incredible endeavors still need to be refined. Echnological programming designers, for example, COMSOL multiphasic are welcome to embed the EC cycle in their electro-chemistry module.

Jean Nepo Hakizimana et al.(2017) studied EC is very hoping technique to treat water from many sides ,simple process , minimal expense, eco-accommodating, flexible, productive, and it is likewise a vague method, ready to eliminate practically a wide range of contaminations all the while. In the last

decade the EC has spread widely in treating the waste water and drinking water as well however the experimental still pure and theoretical research is spastically such as (RSM) to optimize the operation conditions ,the open vertical –plate still the common used reactor. the principle shortcoming of this philosophy is as yet the absence of understanding the associations of various cycles included. In spite of the different unique demonstrating approaches created somewhat recently, for example, VOK or inconvenience models, the connection with buoyancy or settling proficiency, and a more broad scale-up system is still to characterize for EC measure. CFD appears to be ready to fill the hole between phenomenological models and information based models utilizing connections got from CFD information, for instance in techno-financial examination.

Armando et al. (2013) studied the Primary potential and current density distribution analysis. The researchers found out that the current and the potential are not distributed equally and there is increasing in the current density at the surface of the electrodes. The accumulation of energy cause higher and lower areas of current density from the current that been applied. He result that the putting the isolation on the anode can help to rearrange the is potential lead to more uniform of current density distribution .The theoretical studies for the primary current and potential can give a clear idea about to design the EC reactor .These studies predict the effect of the changing in the parameters .In their study they found out that by enhancing the distribution of current density that could lead to more efficient energy use .In this study ,COMSOL multiphasic3.5 had been used to simulate the process.

Rimeh Dagherir et al.(2013) studied the viability of a half and half cycle consolidating electrocoagulation and electro-oxidation for the treatment of homegrown wastewaters utilizing RSM .In this study the batch flow was used to study the removal of DWW utilizing aluminum or iron as bipolar electrodes and

sacrificial anode Gr was utilized as monopolar of homegrown wastewaters utilizing reaction surface procedure. It was found that current density and the time are the most important factors . Design Expert 7.1 program software (Design Expert 7, 2007, Stat-Ease Inc., Minneapolis).

Amani-Ghadim et al.(2013) studied enhancement the EC measure for elimination of an azo color utilizing (RSM)and examination on the event of dangerous aspect reaction. Eliminate of the C.I. Receptive Red 43 dye from fluid was demonstrated and enhanced utilizing response surface method . The ideal conditions, proposed by the RSM, for the greatest expulsion of RR43 in EC utilizing aluminum anode varied from EC-Fe measure. The outcomes acquired from UV–Vis spectroscopy, examination affirmed that the debasement of the dye by EC-Fe measure was conceivable as a minor pathway. In the current work, Minitab programming was used to decide the ideal upsides of the elements.

Saidat Olanipekun Giwa et al.(2012) studied the impacts of operating boundaries on temperature and electrodes correction in electrocoagulation treatment of petrochemical waste water, they presumed that, increase in current density reach increasing in anode corrosion , temperature and energy utilization. However, that of energy utilization isn't alluring as it prompts high working expense. While anode corrosion and energy utilization were influenced by variety of electrolysis time, its single impact on temperature was not critical inside a scope of 10-45 min, yet this was additionally current density subordinate. In the investigations did at high current density between 0.099 A/cm^2 and 0.395 A/cm^2 temperature was seen to fluctuate straightly with time. Variety of NaCl concentration altogether influenced solution temperature and energy utilization. Increase in NaCl concentration diminished both energy utilization and solution .

Wen-Jang Chen et al.(2012) studied continuous flow electrocoagulation for MSG wastewater treatment using polymer coagulants via mixture-process design

and response-surface methods. In this work the decolonization of melanoidin-containing MSG wastewater depends on the less energy and life time of electrodes. In this study the experiment and theoretical studies were depended, the theoretical study which is response surface model is used to optimize the process from 59% to 86% to de colorization and 63% to 68% for COD removal in addition the mass loss by iron electrodes and energy consumption by 15%. In this study the STATISTICA 5.5 software had been used to simulate the effect of different parameters.

Erhan Gengec et al.(2012) studied optimization of baker's yeast wastewater using response surface methodology by electrocoagulation. Quadratic model had been developed to estimate the efficiency to remove the COD and TOC then reducing the operation cost. This model is very suitable with experimental work around 95%. The result shows that the optimum module which is RSM is good to achieve the goals which de colorization and COD and TOC removal and minimize the cost. Design expert 8.0.4 software (tested one) was utilized for the measurable plan of examinations and information investigation.

Tugba Olmmez-Hanci et al.(2012) Studied Electrocoagulation of commercial naphthalene sulfonates. In this study the response surface methodology was used with Central Composite Design. In this study the RSM method was good to design and operate the reactor to remove K acid, COD and TOC then reducing the operation cost. The optimization module in design-Expert software had been used in this research. The maximum result was obtained at PH more than 11, at PH 7 and 10 where the medium pH more than 11 K-acid, COD and TOD removal was 98%, 91% and 88% respectively at time 150gmin. RSM method was found suitable to remove the COD, K-acid and TOC where the energy consumption was reduced. The main cost was electrodes consumption.

Subramanyan Vasudevan et al.(2012) studied enhancing of EC measure to the synchronous expulsion of Hg, Pb, and nickel from debase water. The ideal conditions were current density of 0.15 A/dm^2 and pH of 7.0 for mercury, lead, and nickel utilizing magnesium alloys as anode and galvanized iron as cathode. The anodic corrosion gives magnesium hydroxide adsorbs on magnesium and dispenses with the mercury, lead, and nickel under 0.05 mg/L . Lagergren model of motor examinations had been depended showed the adsorption is depends upon both magnesium hydroxide and mercury, lead, and nickel obsessions that is second-request active . The adsorption of mercury, lead, and nickel undeniably fit for Langmuir adsorption isotherm rather than Freundlich isotherms. The interaction is endothermic and unconstrained cycle.

Mollinedo-Ponce, et al (2011) studied the evaluation of the effect of the rotational electrode speed in an electrochemical reactor using computational fluid dynamics (CFD) Analysis. In this study the researcher had studied the rotating electrode affecting on the performance of the EC ,in this study the reaction time is decreased with increasing in angular velocity up to 150 rpm, beyond this value the concentration of the Cr(VI) is not affected .The other hydrodynamic parameters which they are connected to the angular velocity could clarify the EC reactors behavior ,when increasing the turbulence intensity and z-vorticity along the flow field ,enhance mass transfer which lead to decreasing the time.

Manpreet S. Bhatti ,et al. (2011) studied the displaying and advancement of voltage and treatment time for electrocoagulation expulsion of hexavalent chromium. The anticipated quadratic model showed a high coefficient of assurance for Cr(VI) expulsion ($R^2=0.975$) and energy utilization ($R^2=0.990$). RSM expectations are likewise approved utilizing the ANN approach. The optimum conditions where 51.9% of Cr had removed were 12.9V , 19.2 min and 12.8 Wh.

Bennajah Mostafa Maalmi et al.(2010) studied the oily wastewater ordination of drinking water by electrocoagulation/electro flotation. In this study the a variable order kinetic (VOK) which is taken from Langmuir-Freundlich correlation created to modeled the reactions of the defluoridation with EC using bipolar aluminum electrodes in the airlift reactor. The result were clarify the good correlation between what estimated and experimental result. In this study some of critical parameters keep them constant like q_{\max} (best fluoride removal) and K (kinetic constant) while the other been changed (initial fluoride concentration and current) .In this study the external loop reactor was used which reach to the 100% floatation and at same time the recovery of flocs compared with rotating reactors which process need long time.

Ahmed et al.(2010) studied expulsion of lead from wastewater by electrocoagulation technique. In this study the removal of lead from wastewater had been studied ,which many affecting factors been investigated for various affecting factors such as the concentration ,the types of electrodes ,the gap between electrodes and etc. They found that: At pH =9 the best removal in short time, with increasing current density the elimination of pollutants enhanced ,while with increasing the initial lead concentration the efficiency decreased. The Al electrode preferable where about 99.08% of lead had been removed in only 10 min while the 99% in 20 min when using St.St cathode. The maximum removal efficiency is obtained in greater surface area of electrode and shorter distance between them due to decreasing the bubble in the EC cell. When the initial pollutants concentration increase the time to remove them increase consequently .With increasing the flow rate the efficiency decrease.

Vepsäläinen Mikko Vepsäläinen (2009) concluded the following after studied the effects of temperature and initial sample pH on natural organic matter(NOM) .The Aluminum analysis increase with increasing of temperature ,pH

changing during EC process is affected only by initial pH .EC has a little influence on the conductivity of the water .The temperature has a minor effect on the removal of the NOM compared with initial PH and electric charge .

1-Analysis of Aluminum anode increase with temperature.

2-The PH changing during process affected by initial pH .

3-The water conductivity a little affected from 2.9ms/m to 5.2 ms/m

4-NOM removal optimum conditions are pH =4.3 ,T=295.15 K and electrolysis charge is 144 C/L

The energy consumption was 0.4 Kwh/m³

Al consumption 40mg/L

5-The effect of electrical charge and initial PH were much then the effect of temperature.

The NOM removal could be done as well by EC from cold water .

Orathai Chavalpait et al.(2009) studied Optimizing electrocoagulation process for the treatment of biodiesel wastewater using response surface methodology(RSM). In this study the aluminum had been used as anode and graphite as cathode which is useful to remove the O and G (oil and gas)and SS till 95% at same time the COD removal is 55% only for this result the EC could be good as primary treatment method in biodiesel wastewater .The glycerol and methanol are not important ,for this reason the EC could be good for pretreatment for biodiesel water .

Meanseta et al .(2009) studied the pretreatment of sleek wastewater from an unrefined palm oil factory by EC can improve biodegradability of oil consumption ,the EC treatment and biological is better than evaporation or pure physicochemical where required less energy ,shorter in time , without needing for chemicals and little of slug .The Box-Behnken design can reduce the no. of runs to

reach the ideal condition comparison with one time experiment method optimum conditions are :pH=6.06

,V=18.2V and t=23.5 min ,which they met the experiment factors from one time method .From above RSM could be effective in multifactor complex EC.

Mohammed Tir et al.(2008) studied the optimization of oil removal from oily waste water by electrocoagulation using response surface method (RSM).The concluded as following :the efficiency of EC affected by electrolysis time , applied current density and initial pH .

The tests show that the destabilization of pollutants by coagulants Al^{+3} which is result of analysis of anode electrode and formation of flocs.

In this study shows the quadratic model strong relationship between theoretical and experimental result .The optimum conditions are :current density $25mA/cm^2$,initial pH is 7and electrolysis time is 22min.Around 99% of turbidity and 89%of COD have been removed.

2.4 The Literature Review conclusion:

Each material to be removed ,has its own optimum condition. Most of studies used Al as sacrificial anode, because the cheap price and efficient at same time . The efficient of pollutants removal increase with increasing of the applied voltage ,temperature and time. The theoretical studies helps to improve the process ,optimum the condition and decrease the prices.

- 1- EC has great future for water treatment however the studied need to be done in order to optimize the conditions ,to minimize the coast .
- 2- Al used as anode in most of cases ,due to efficient ,cheap and availability .
- 3- The pollutants removal efficient increase with increasing the applied voltage and current density .

2.5 Summarize Literature Review

No.	Author	Year	Modeling type	Electrodes	Software	Kind of pollutants	Notes.
1	Andrii Safonyk	2019	CFD	Al	SCADA	Nickl	The robotization control framework with P-controller can ration up to 21.4% of power costs
2	Andrii Safonyk	2019					The method of the solution can be utilized to break down the impact of heat and mass transfer and kinetics of the reaction ,the experimental and theoretical studied to optimum the condition in the EC .
3	Abdulaziz Alghamdi, et al.	2019					Review the models for EC
4	Jean Nepo Hakizimana	2017	CFD	Al			CFD can link between the simulation and experimental by using the equation then solving them
5	Rimeh Dagherir	2013	RSM	Al	Design expert 7.1	DWW	U-sing aluminum or iron as bipolar electrodes and sacrificial electrodes Gr was used as monopolar .It was found that current and how long it's take are the most important factors .
6	Armando	2012		Al	Comsol multip	COD and BOD	Studied the Essential potential and current density distribution investigation. The researchers

					basics 3.5		found out that the current and the potential are not distributed equally and there is increasing in the current density at the surface of the electrodes. The accumulation of energy cause higher and lower areas of current density from the current that been applied
7	Wen-Jang Chen	2012	RSM	Fe	Statistica 5.5	MSG and COD	In this work the de colorization of melanoidin-containing MSG wastewater depends on the energy consumption and life time of electrodes .In this study the experiment and theoretical studies been depended ,the theoretical study which is response surface model is used to optimize the process from 59% to 86% to de colorization and 63% to 68% for COD removal in addition the mass loss by iron electrodes and energy consumption by 15% .In this study the STATISTICA 5.5 software had been used to simulate the effect of different parameters .
8	Erhan	2012	RSM	Al	Design expert 8.0.4	COD and TOC.	Efficiency to remove the COD and TOC then reducing the operation coast .This model is very suitable with experimental work around 95% .The result shows that the optimum module which is RSM is good to achieve the goals which de colorization and COD and TOC removal and minimize the coast .The Design Expert 8.0.4gsoftware was used for the statistical design of experiments and data analysis.

9	Tugba	2012	RSM	stainless steel	Design expert	K-acid, COD and TOC	The enhancement unit in Design-Expert software had been used in this research. The maximum result was obtained at PH more than 11, at PH 7 and 10 where the medium PH >11 K-acid, gCOD and TOD removal was 98%, 91% and 88% respectively at time 150 min.
10	Subramanian Vasudevan	2012		Magnesium alloy as anode Galvanize iron as cathode		Mercury, lead and nickel	The pollutants removal from Hg, Ni and Pb is good when using Langmuir isotherm adsorption, with increasing in process temperature
11	Saidat Olanipekun Giwa et al.	2012		Al	Design Expert 7.0.0		Increasing in temperature, electrodes corroding and energy used as result to increasing in current density
12	Helvio	2011	CFD	Fe	Fluent CFD software	Cr	In this study the researcher had studied the rotating electrode affecting on the outcome of the EC, in the research the reaction time is decreased with increasing in angular velocity up to 150 rpm, beyond this value the concentration of the Cr(VI) is not affected
13	Manpreet	2011	RSM	Al	MATLAB computing environment	Cr	Simulation and advancement of voltage and treatment time for electrocoagulation evacuation of hexavalent chromium.
14	Ahmed A. Moha	2010		Al anode		Lead	The maximum removal efficiency is obtained in greater surface area

	mmed and Muhammed			And ST.ST as cathode			of electrode and shorter distance between them due to decreasing the bubble in the reactor .With expanding the lead concentration the time needed to remove it is higher .With increasing the flow rate the efficiency decrease.
15	Bennajah Mostafa Maalmi	2010	VOK	Al		Oil	In this study the a variable order kinetic (VOK) which is taken from Langmuir-Freundlich condition made to modeling the energy of the DE fluoridation with EC utilizing bipolar aluminum terminals in the carrier reactor. The result were clarify the good correlation between what estimated and experimental result.
16	Mikko	2009	RSM	Al		NOM	1-Analysis of Aluminum anode increase with temperature. 2-The PH changing during process affected by initial pH . 3-The water conductivity a little affected from 5-The effect of electrical charge and initial PH were much then the effect of temperature.
17	Orathai and Maneerat	2009	RSM	Al		O&G, SS and COD.	RSM could be effective in multifactor complex EC.
18	Mohammed and Moulai	2008	RSM	Al		Oil	The efficiency of EC affected by electrolysis time , applied current density and initial pH .
19	H. Ashassi-Sorkhabi		RSM		Minitab	Azo	The best working conditions , proposed by the RSM, for the most extreme expulsion of RR43 in EC utilizing aluminum anode varied from EC-Fe measure. The

							outcomes got from UV–Vis spectroscopy, TOC and GC–MS examination affirmed that the debasement of the color by EC-Fe measure was conceivable as a minor pathway.
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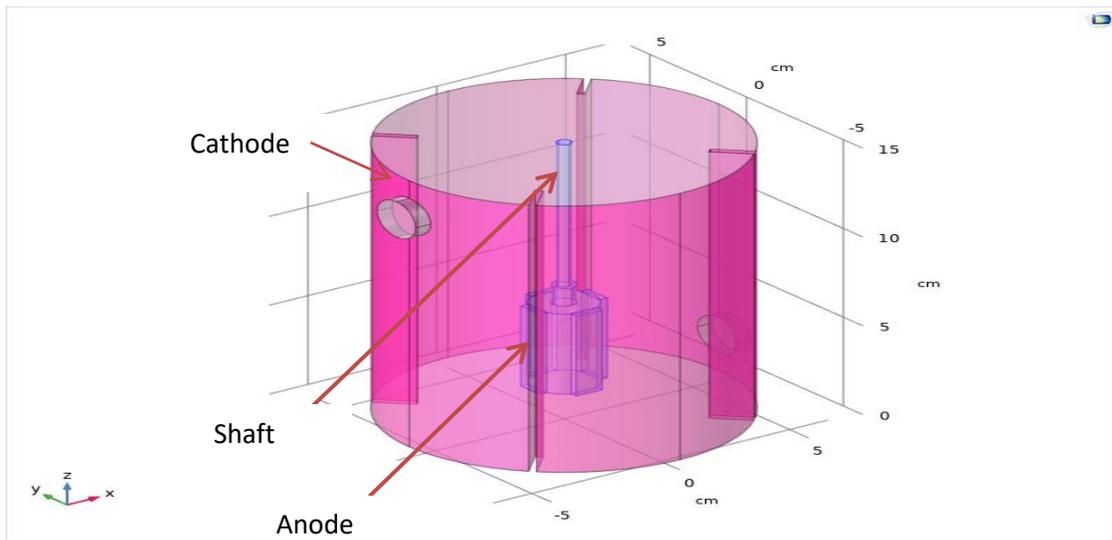
Chapter Three: Theoretical Work

3.1 Introduction

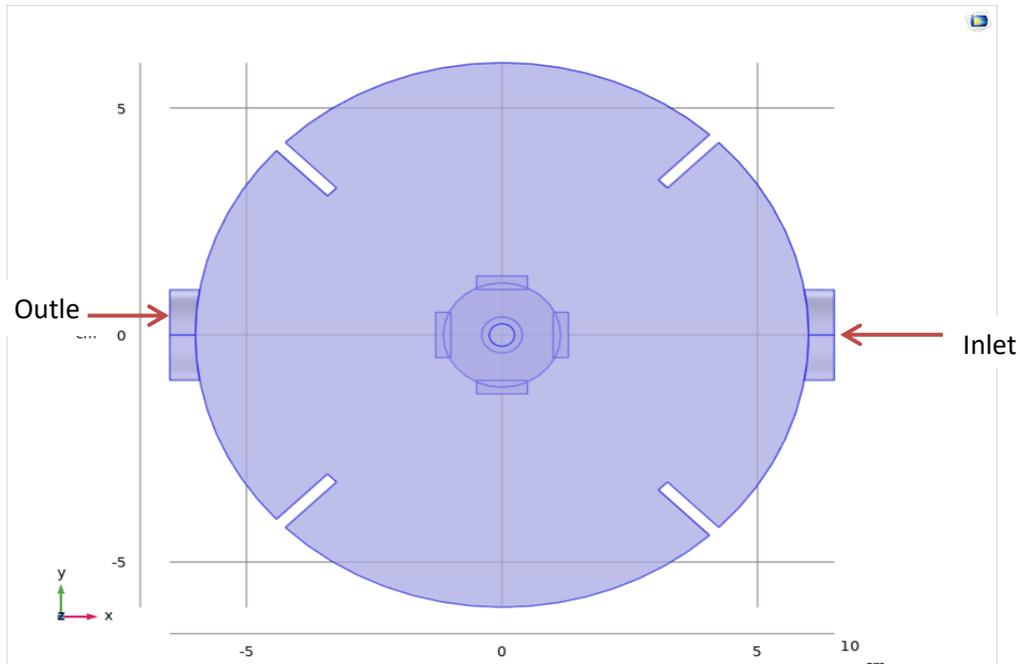
This chapter discusses the theoretical work, which dealing with solving the differential equations for four physics ,secondary current distributions ,laminar flow ,heat transfer in fluid and mass transfer in dilute species to simulate the EC process by using COMSOL multiphasic program. .Different parameters influence are going to be discussed in this chapter on the EC process ,like temperature ,voltage ,time and current.

3.2 Geometry And Coordinate System

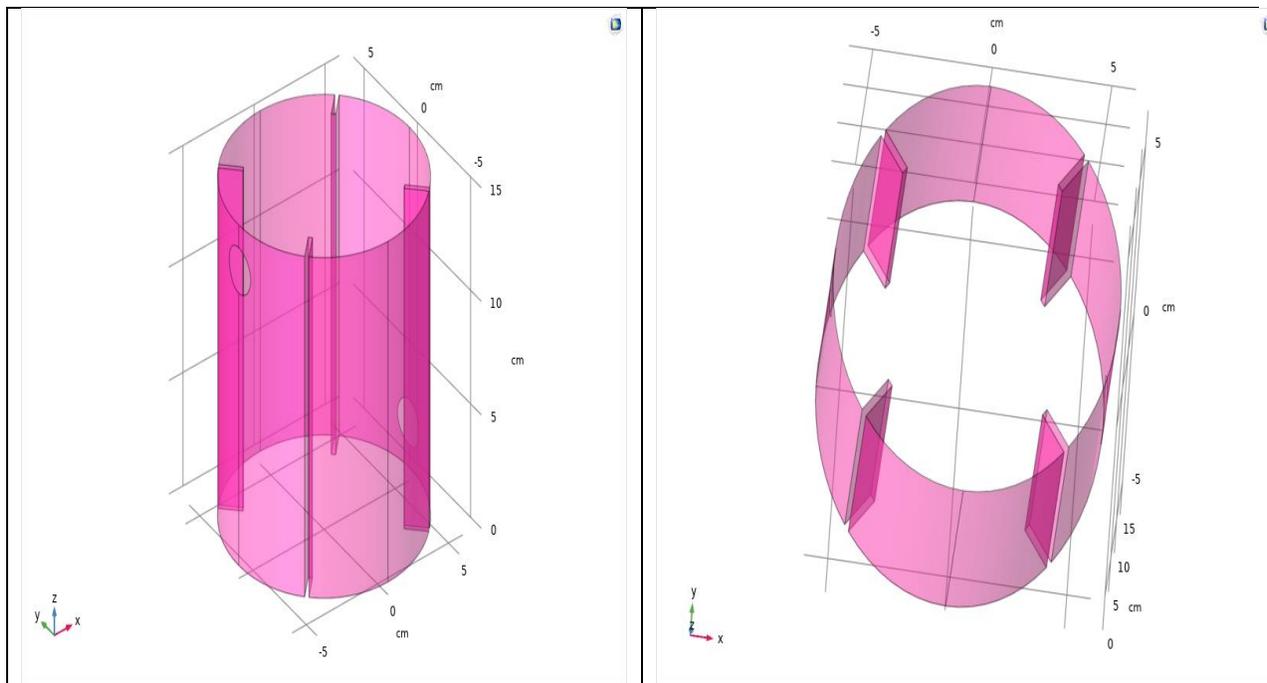
The parts of EC reactor are a cylinder it's dimensions ,the radius is 5 cm and height is 15 cm ,the inlet of the reactor near the bottom side while the outlet near the top the reactor .The anode is represented by the rotating domain connected with a shaft and the cathode is the rest of the reactor .



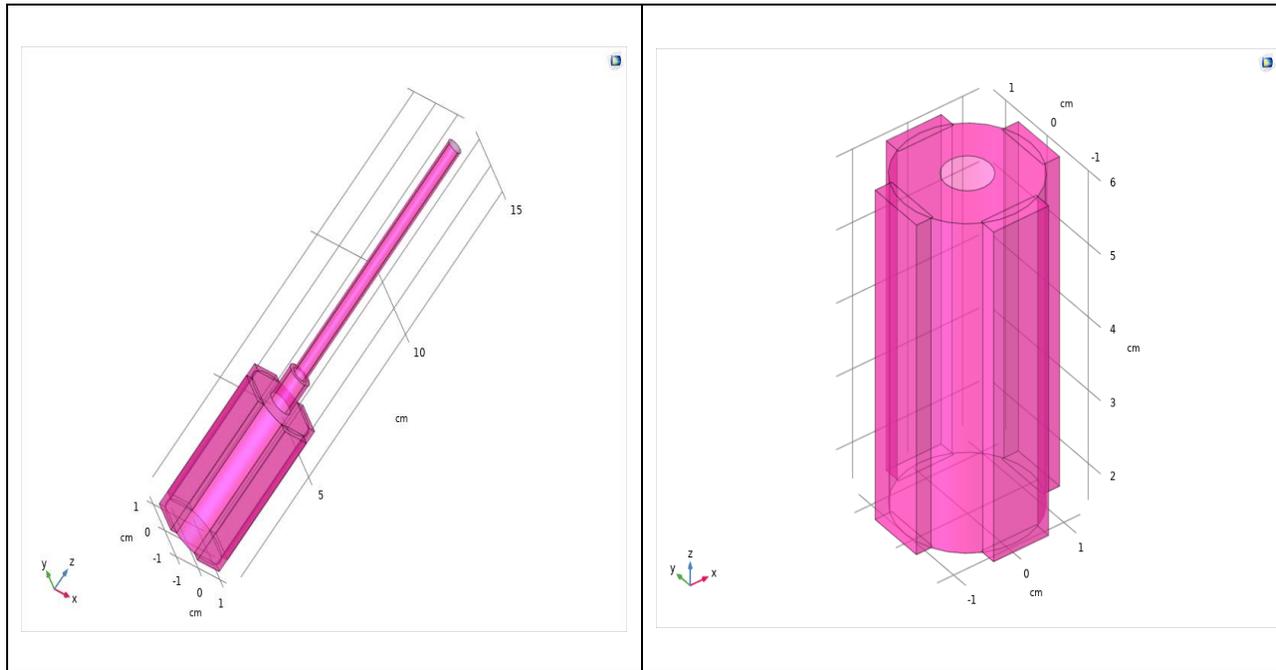
FIGURE(3.1). The EC Reactor Of The Present Work.



FIGURE(3.2). The EC Reactor Of The Present Work(top view).



FIGURE(3.3). Cathode of EC reactor.



FIGURE(3.4). Anode of EC reactor.

3.3 Assumptions

- 1-The work scope in the 3D.
- 2-Laminar flow .
- 3-Non isothermal process.
- 4-Newtonian Fluid .
- 5-The current density and flow under steady state
- 6-The concentration and heat under time dependent .
- 7-Constant pH

3.4 Governing Equations

In this research the mass ,heat and current transfer are the governing equations ,the numerical solutions for the partial differential equation are depended in this research ,the transfer phenomena are the base of this research ,mass ,heat ,ions, and current .

3.4.1 Equation Of Momentum Transfer

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} = 0 \quad (1)$$

General momentum equation

$$\rho \frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u = \nabla \cdot [-pI + \mu(\nabla u + (\nabla u)^T)] + F \quad (2)$$

(x direction)

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = g - \frac{\partial}{\partial x}(Ip) + \mu \left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right] + F_x \quad (3)$$

(y direction)

$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) g = g - \frac{\partial}{\partial y}(Ip) + \mu g \left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right] + F_y \quad (4)$$

(z direction)

$$\rho \left(\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) g = g - \frac{\partial}{\partial z}(Ip) + \mu \left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right] + F_z \quad (5)$$

p pressure (Pa),

ρ density (kg/m³),

F volume force vector (N/m³),

μ dynamic viscosity (Pa.s),

u mean velocity (m/s) **Huda 2020.**

Boundary Conditions

$$u_0 = u_{in}$$

And the initial pressure condition is equal zero ($p_0 = 0$)

3.4.2 Ionic Species Mass Transfer

All kinds of mass transfer are in the EC system, convection ($C_i u$), as well as electro-migration ($Z_i u_{m,i} F C_i \nabla \varphi$) and diffusion ($D_i \nabla C_i$). The mass transfer flux of species i is given by Nernst-plank equation .

$$N_i = -D_i \nabla C_i - Z_i u_{m,i} F C_i \nabla \varphi + C_i u \quad (6)$$

N_i : flux of the chemical species due to convection, D_i : diffusion coefficient

,Huda 2020

Described by Arrinhuis equation :

$$D_{(T)} = D_0 \exp \frac{-\Delta E}{RT} \quad (7)$$

C_i g average concentration.

Z_i g charge number.

$u_{m,i}$ mobility of I species which

Describe by Nernst-Einsteine equation :

$$Um. i = \frac{Di}{RT} \quad (8)$$

φ electric potential.

The charge and species conservation by following :

$$\frac{\partial C_i}{\partial t} = -\nabla N_i + R_i \quad (9)$$

$$\frac{\partial C_i}{\partial t} = D_i \left[\frac{\partial^2 C_i}{\partial x^2} + \frac{\partial^2 C_i}{\partial y^2} + \frac{\partial^2 C_i}{\partial z^2} \right] + Z_i u_{m,i} F \left[\frac{\partial \varphi}{\partial x} \left(\frac{\partial C_i}{\partial x} \right) + \frac{\partial \varphi}{\partial y} \left(\frac{\partial C_i}{\partial y} \right) + \frac{\partial \varphi}{\partial z} \left(\frac{\partial C_i}{\partial z} \right) + C_i \left(\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} \right) \right] - \left[u \frac{\partial C_i}{\partial x} + v \frac{\partial C_i}{\partial y} + w \frac{\partial C_i}{\partial z} \right] + R_i \quad (10)$$

R_i reaction rate of species i, **Huda 2020.**

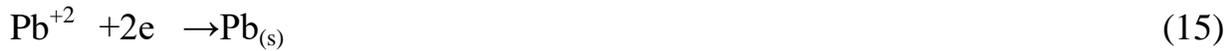
Electrodes Reactions.

Typically the iron or aluminum are used as electrodes in the EC cell as plates, which they are the source of coagulant .Once the current apply on the electrodes of EC the anode is oxide while the cathode is react where the H2 is liberate causing increase in PH of solution.



At Al anode





Bazrafshan et al, 2015.

By Faraday's law of electrolysis we can estimate the amount of metal dissolved from the anode, there is relationship between current and amount of metal release from the anode.

$$m = \frac{ItW}{nF} \quad (17)$$

Where:

m : mass - g.

I : current - A.

t : - seconds.

W : - g mol.

N : valence of dissolution.

F : Faraday's constant (96,4850 C mol).

Boundary Conditions

The initial mass transfer value is zero for both anode and cathode .

The anode is corroded base on the following equation:

$$N_i = \frac{i}{ZF}$$

i is the electrolyte current density, Z is valence no.

F Faraday constant)

Initial concentration

$$C_{i,\text{Aluminum hydroxide}} = 0, C_{i,\text{pollutant}} = C_0$$

3.4.3 Voltage And Current Distribution

In the present research the secondary current distribution had been studied:

$$\nabla \cdot i_l = Q_l \quad , \quad i_l = -\sigma_l \nabla \phi_l \quad (18)$$

$$\frac{\partial i_l}{\partial x} + \frac{\partial i_l}{\partial y} + \frac{\partial i_l}{\partial z} = Q_l \quad , \quad i_l = -\sigma_l \left(\frac{\partial \phi_l}{\partial x} + \frac{\partial \phi_l}{\partial y} + \frac{\partial \phi_l}{\partial z} \right) \quad (19)$$

σ_l : the conductivity of electrolyte (S/m), ϕ_l : the electrolyte potential (V).

Boundary Conditions

At anode $\quad \phi_{s,ext} = E_{cell}$

At cathode $\quad \phi_{s,ext} = 0$

3.4.4 Heat Transfer

3.4.4.1 Heat Transfer In Liquid

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p U \nabla T + \nabla \cdot q = Q + Q_p + Q_{vd} \quad (20)$$

$$q = -K \nabla T \quad (21)$$

Where:

Q_p =The work done by the pressure changes.

Q_{vd} =Viscose dissipation in the fluid .

3.4.4.2 Heat Transfer In Solid

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p U \nabla T + \nabla \cdot q = Q + Q_{ted} \quad (22)$$

$$q = -K \nabla T$$

Initial Conditions

$$T = 239.15 \text{ K}$$

k : thermal conductivity, W/(m·K)

c_p : specific heat capacity, J/(kg·K)

ρ : density, kg/m³

3.5 Adsorption Isotherm Model

One of the most popular mechanism that proposed to better understanding on EC is Langmuir adsorption Huda 2020

$$\text{Langmuir isotherm: } q_e = q_{\max} \frac{K_L C_e}{1 + K_L C_e} \quad (23)$$

Pollutants removal is represented in following:

$$-\frac{dC_t}{dt} = \varepsilon_M q_e \frac{dM_{\text{tot}}}{dt} \quad (24)$$

M_{tot} is the total aluminum amount transfer which is come from the anode which can be identified by Faraday's law association with ε as current yield.

$$\frac{dM_{\text{tot}}}{dt} = \varepsilon \frac{I}{ZFV} \quad (25)$$

Langmuir adsorption isotherm to remove the lead is:

$$-\frac{dC_t}{dt} = \varepsilon_M \cdot \varepsilon \frac{I}{ZFV} q_{\max} \frac{K_L C_e}{1 + K_L C_e} \quad (26)$$

$$K_{L(T)} = K_{L_0} \exp \frac{-\Delta E}{RT} \quad (27)$$

V is the volume of solution.

F Faraday's constant,

K_L Langmuir constant

C_e equilibrium adsorbate concentration in water

$e\varepsilon$ current efficiency

Z valence of the electrode metal

I applied current, ,

q_{\max} adsorption capacity / metal cations

q_e amount of adsorbed / adsorbent at equilibrium.

ε_M efficiency of hydro-pollutant-aluminum formation.

3.6 COMSOL Multiphysics

COMSOL multi-physics is a software that deals with finite elements solver, simulate different physics base on solving of the differential equations (PDEs). It deals with multi-physics like mechanical, electrical, chemical, electrochemical, fiber, plasma, optics, semiconductors, etc. It has many feature, it can coupling physics at same time, **COMSOL**.

It enable the users to build his own element base on the study requirements, so he can choose the his study while in 1D, 2D or 3D where the problem become more complex and realistic. The user can choose the study while its stationary or time dependent. It has a library of the martial with its physical properties, users can add the properties and parameters.

3.7 Scope Of COMSOL

COMSOL multi-physics is a tool to solve the PDEs for the physics, simulate the behavior of the material and process in virtual way. It's used by researchers and specialist to make the problems solutions easier and accurate, the version COMSOL 5.5 is used in this thesis, **COMSOL**.

3.8 Problem Type Specification First step is to choose whether the model wizard or blank model, then space dimension one of the following option the dimension problem, whether its one dimension, two dimensions or three dimensions. Then, next step to select the physics then select the study (stationary, time dependent or empty study).

3.9 Geometry Creation

The first thing after choosing the basic requirements for the problem is to create the equipment that will be used in the problem, there are good tools provided by COMSOL, under option geometry to implement that. The current geometry consist

of two domain ,which one is rotating (Anode)while the other is stationary (Cathode) which already has been described in the introduction of this chapter .

3.10 Mesh Generation

The mesh choosing is based on the accuracy of the result that want to reach ,where the finer mesh could give more accurate result ,however some time not the finest mesh is the better choice depending on the solutions of the equations that deal with equipment ,if the user face an error to solve the problem then he need either make the mesh coarser or tolerance bigger .The mesh contains of 86324 elemnts,1240 edges,8652 triangles and mesh volume is 1675 Cm³ .

3.11 Defining The Physics On The Domains

Selection the domain that will be the physics process, then you can insert the variable ,or you can choose the that from material .

3.12 Application Of COMSOL Multiphysics

The current research is a sample equipment consist typically from rotating anode and cathode which is the wall of the equipment ,it has two domain ,the rotating which anode and the stationary which the cathode ,it has 76 boundaries ,128 points and edges, see figure below.

After crating the geometry of the module ,the parameters had been added where the variables been put and their value in the parameters field .Then the physics have been used which they are four ,Laminar flow ,secondary current distribution ,heat transfer and transfer of dilute species .The laminar flow had been used to describe the flow where the process is continuous ,the secondary current distribution to add the voltage and current to the anode and cathode, the heat transfer to show the heat influence on the process and the transport of dilute spices to describe the adsorption and diffusion of the coagulant and pollutants .

Three kind of studies have been depended ,the stationary which describe the current distribution where the current became study state with no longer time considered ,the frozen rotor to describe the laminar flow and time dependent to study the heat and mass transfer .

The process in conclusion started to liberate the Al ions from rotating anode to the electrolyte ,the OH ions formed in the cathode ,they reacting to create the Al(OH)₃ The Al hydroxide reacting with the pollutants. Typically the result as below, figure(3.2,3,4,5,6,7,8 and 9) show the mesh of the EC reactor , velocity distribution , pressure ,electrolyte potential , current distribution , coagulants concentration ,lead concentration distribution and ,temperature distribution respectively.

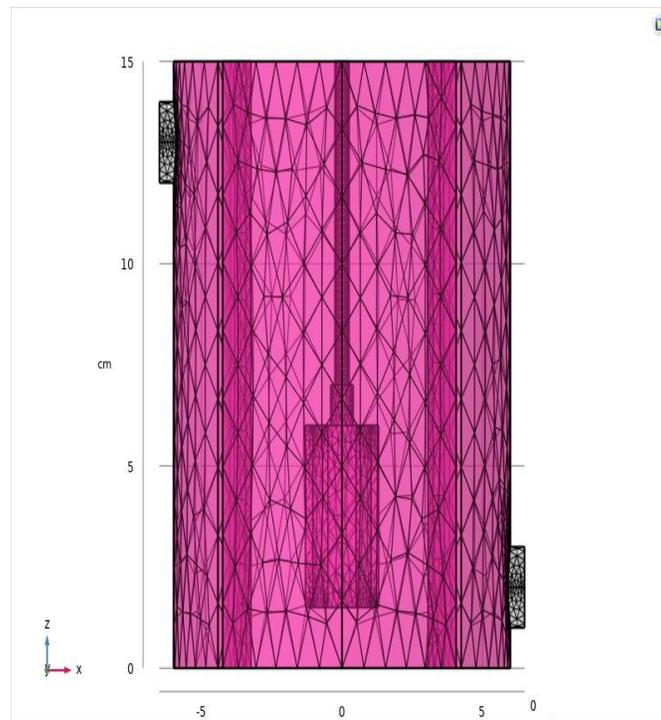
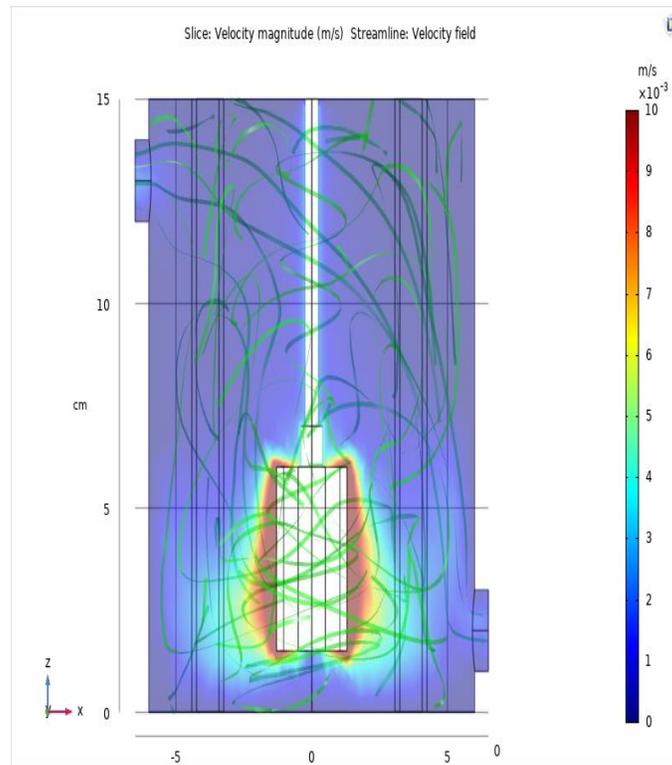
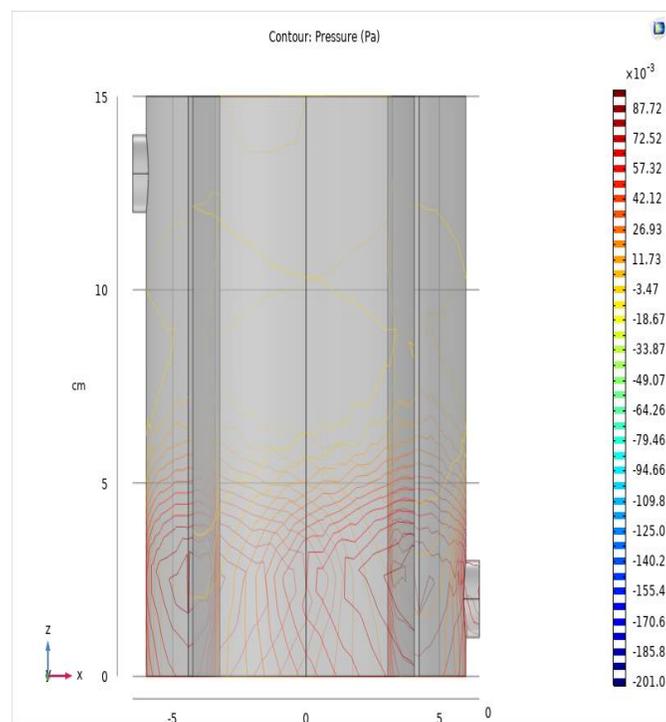


Figure (3.5) mesh in the in EC reactor

**Figure (3.6)** Velocity distribution**Figure (3.7)** Pressure distribution in the in EC reactor

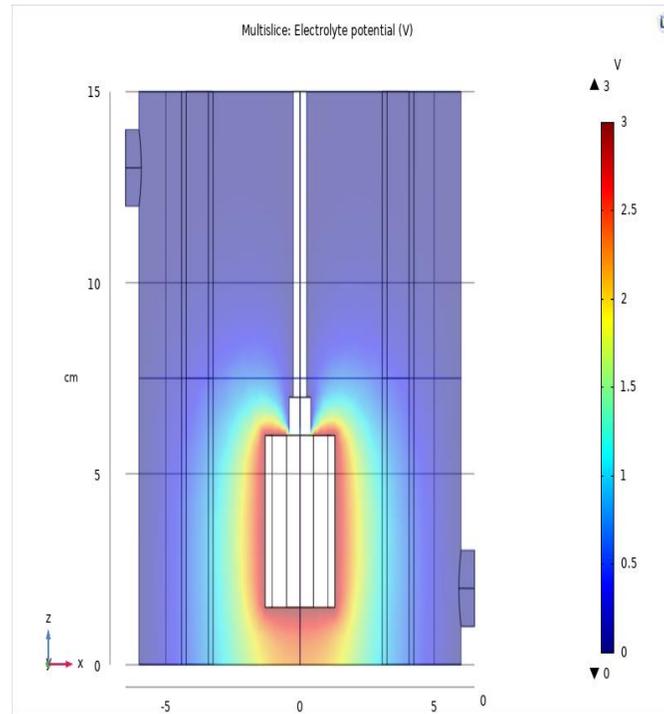


Figure (3.8) Electrolyte potential distribution

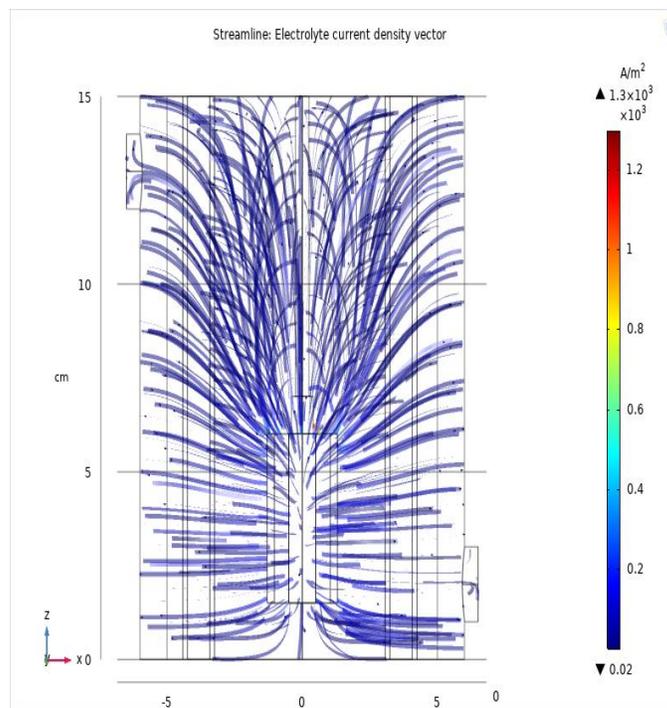


Figure (3.9) Current density distribution in the in EC reactor

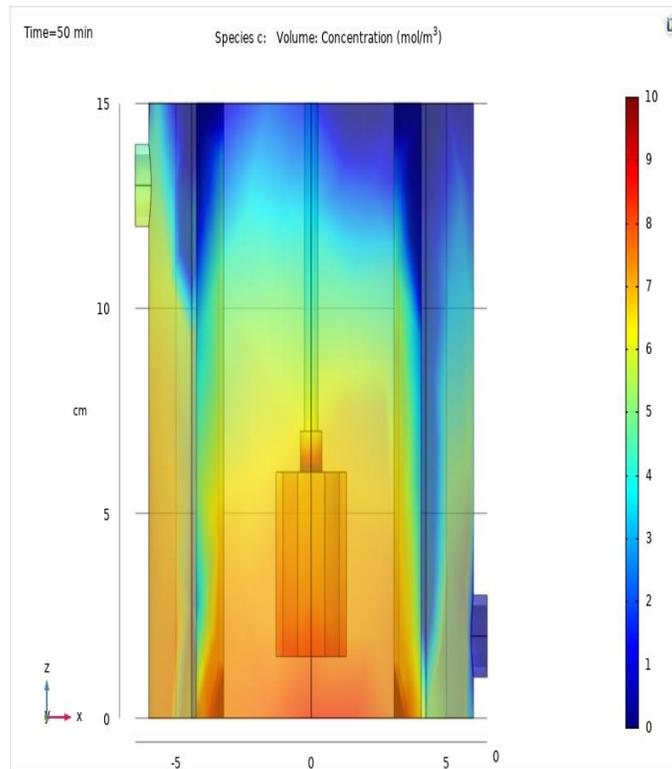


Figure (3.10) Coagulants concentration distribution

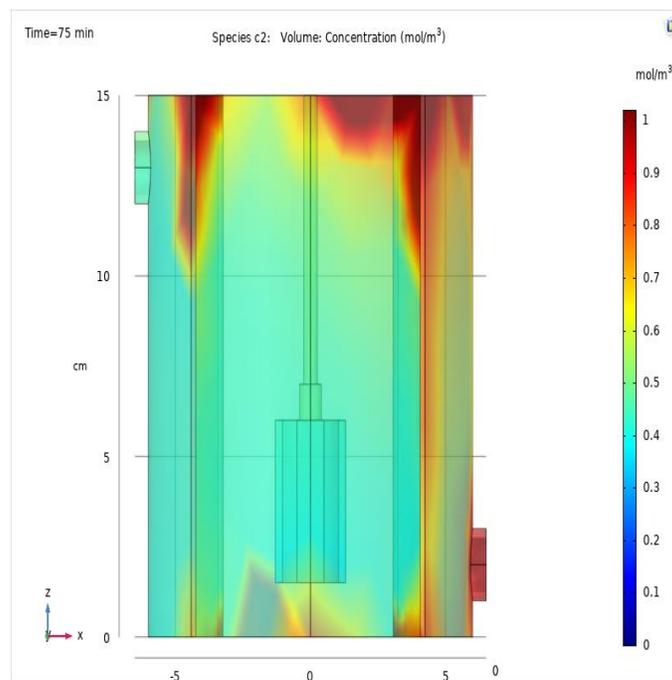


Figure (3.11) Lead concentration distribution

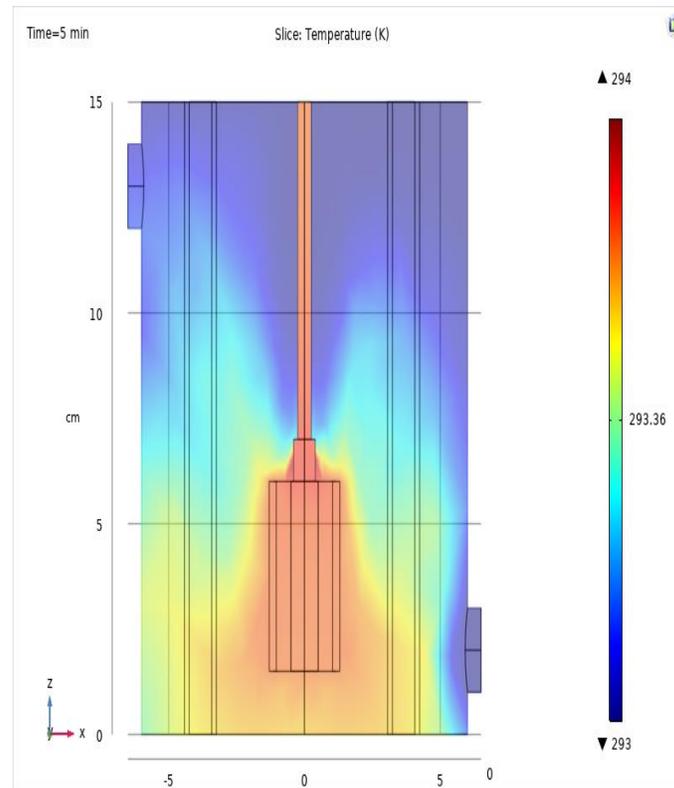
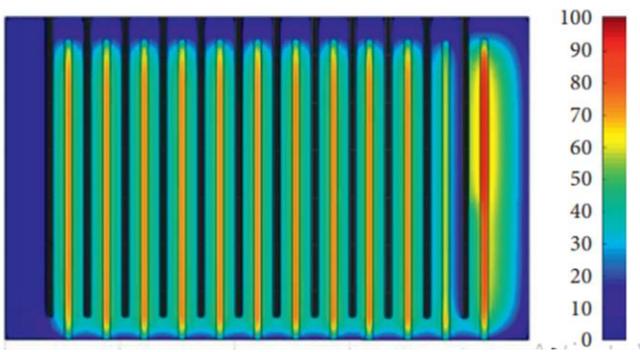


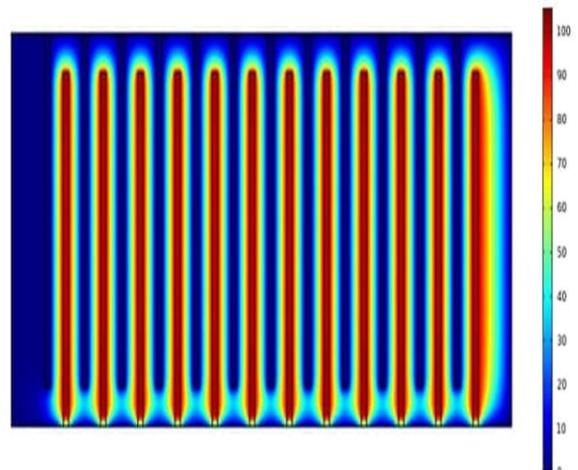
Figure (3.12) Temperature distribution

3.13 Verification Example

Andrii et al (2019) had studied the EC by simulating non isothermal condition of incompressible fluid by using general form of partial differential equations to the physics to predict the behavior of the process in the cell, which consist of 12 cathode and 12 iron anode ,the current strength influence, the heat generation were studied .



FIGURE(3.13). Temperature Distribution In Andraii's Work



FIGURE(3.14). Temperature Distribution in Verification

Chapter Four: Results And Discussion

4.1 Introduction

This chapter details the results of solving partial differential equations involving momentum, mass transfer, secondary current distribution and heat transfer equations to estimate the lead removal by using the software COMSOL multi-physics 5.5 was employed to solve these equations. The aim of the study is to determine the influence of different parameters influence on lead removal including hydraulic retention time (HRT), the rotational speed (rpm) and the applied voltage (V). The basis are pollutant (lead) concentration is (1 Mole/ M³), initial temperature of (293.15 K), The rotational speeds (0, 10, 50 and 100 rpm), and the applied voltages (1.5, 3, 6 and 10 V).

4.2 Voltage Distribution

Figure(4.1) below shows the voltage distribution at applied voltages of (1.5, 3, 6 and 10 V) as boundary condition at anode and zero at cathode to solve the current equation, at steady state.

The maximum voltage around the anode goes towards the cathode. This is the boundary condition of secondary current distribution which assuming that the Ecell (1.5, 3, 6 and 10 v) at the anode and zero at the cathode. The distance above anode (above 8cm) doesn't have effect which is the flocs area in which the flocs going up. the area around anode is the most effective area in which the reactions is starts then transfer to the rest of the reactor, because the voltage and current is max at this area.

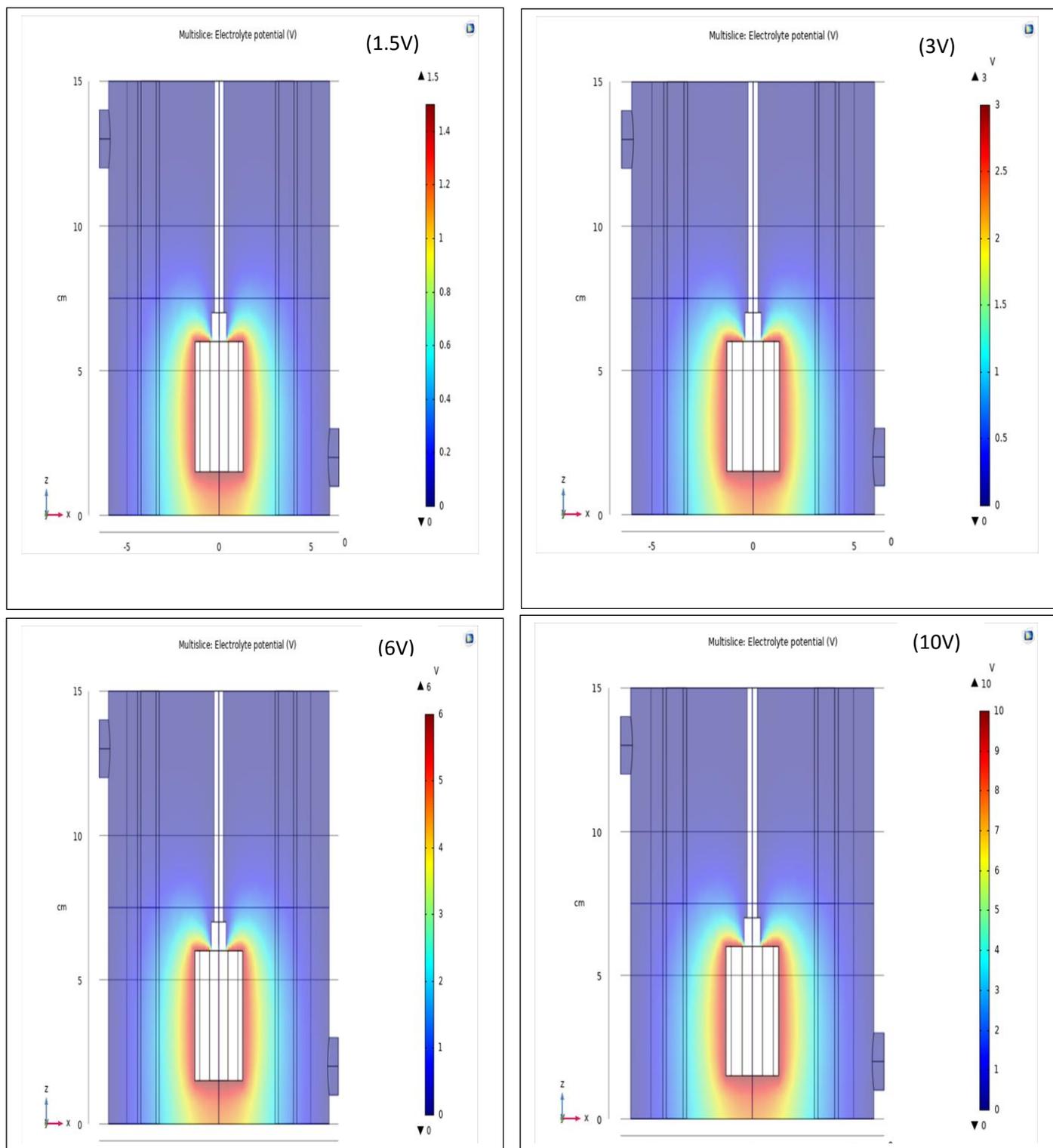


Figure (4.1) Voltage distribution in the EC reactor of applied voltages of 1.5,3,6 and 10 V.

4.3 Current Density Distribution

Figures(4.2 and 3) below show the distribution of current density in the EC reactor at applying voltages 1.5,3,6 and 10 V as boundary condition at anode and zero at the cathode to solve the current equations, at steady state. The current source is from anode to cathode. The current density increases as applied voltage increases as in the table below, the current density starts from anode which is maximum value towards cathode which is minimum, based on the boundary condition see table(4.1) .The area around anode is most active area in the reactor ,in which the reaction starts then transfer to the rest of reactor as result of high current density then high coagulants production.

No.	Applied Voltage (V)	Max Current Density (A/M ²)
1	1.5	694
2	3	1300
3	6	2590
4	10	4320

TABLE (4.1) Current densities at different applied voltages.

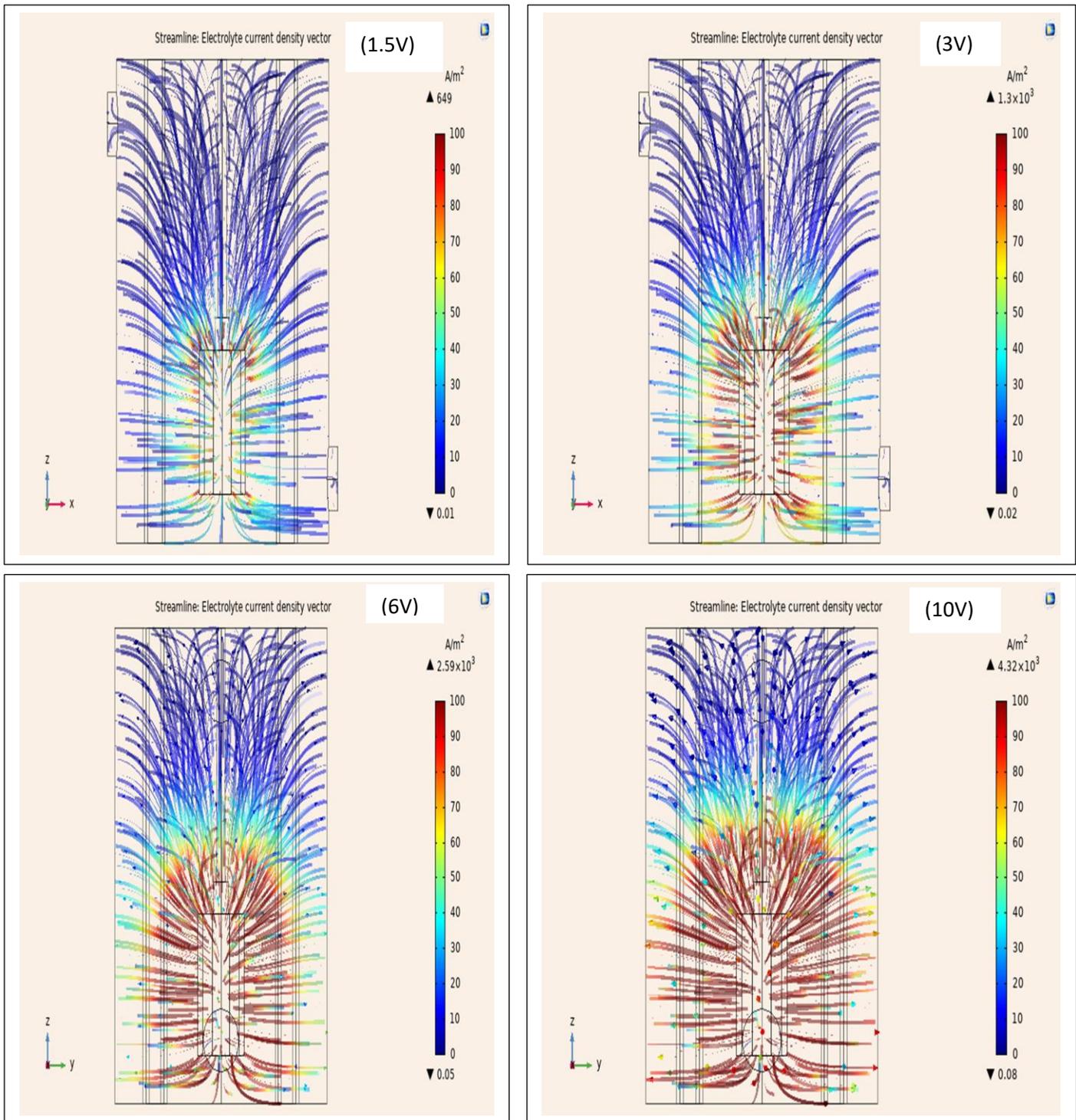


Figure (4.2) Current distribution(side view) in the EC reactor at applied voltages of 1.5,3,6 and 10 V.

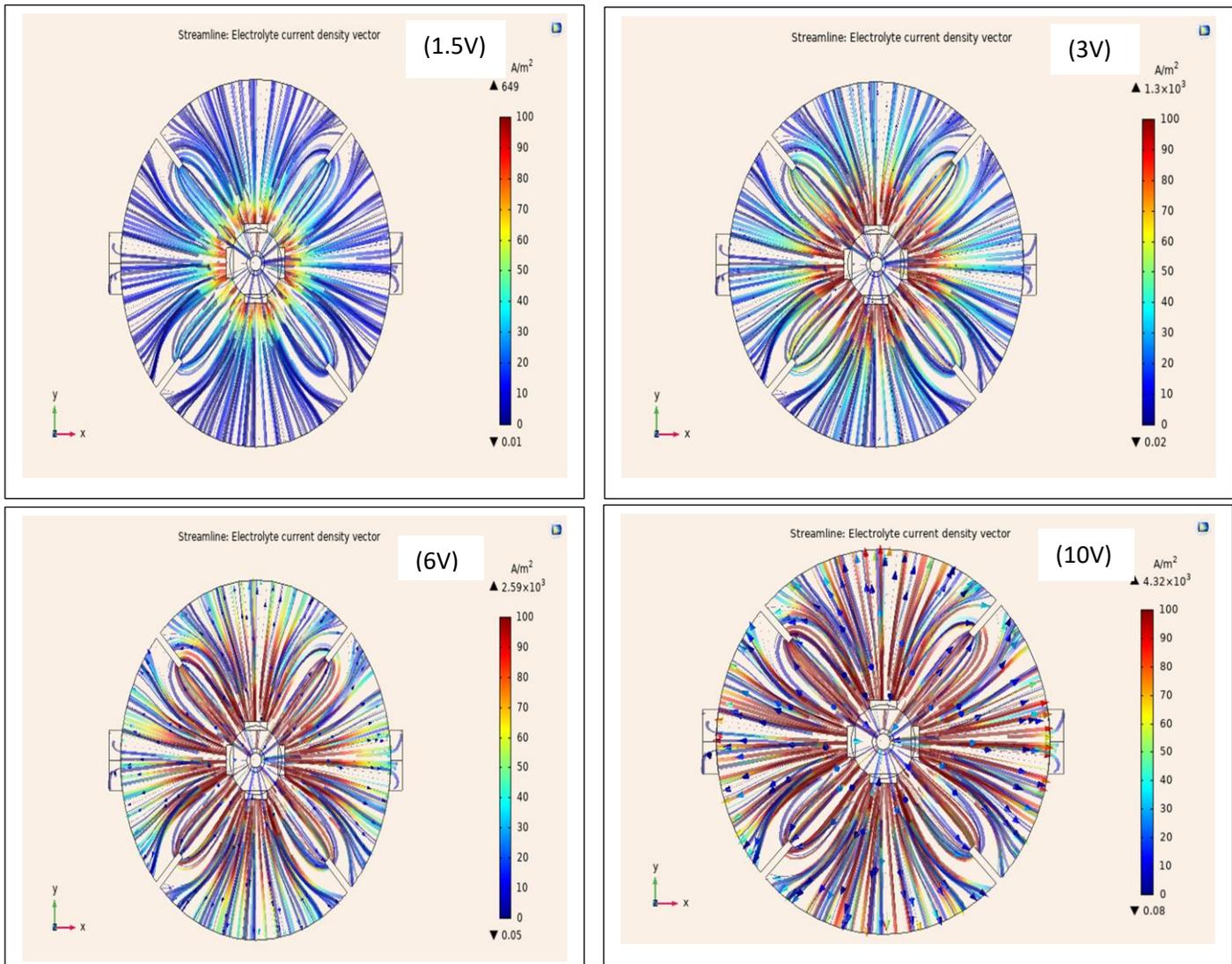


Figure (4.3) Current (top view) distribution in the EC reactor at applied voltages of 1.5,3,6 and 10 V.

4.4 Velocity Distribution

Figure(4.4) below shows the velocity distribution in EC reactor, when solving the momentum equation at different rotational speeds 0,10,50 and 100 rpm. At anode rotational speed of zero, the maximum velocities are at the inlet and outlet of reactor, which is around 0.002 M/S, the flow rate of the polluted water only. As the velocity distribution is varied by varying anode speeds (10,50 and 100 rpm) , the velocity is maximum around the anode because the movement starts from anode to the rest of reactor, which helps to mix the electrolyte ,the maximum speeds in **Table (4.2)** against the rotational speeds ,which help mix the coagulants and pollutants too .

No.	Rotational Speed (rpm)	Velocity M /S
1	0	0.002
2	10	0.01
3	50	0.07
4	100	0.14

TABLE (4.2) The Rotational speed (rpm) VS velocity (M/S)

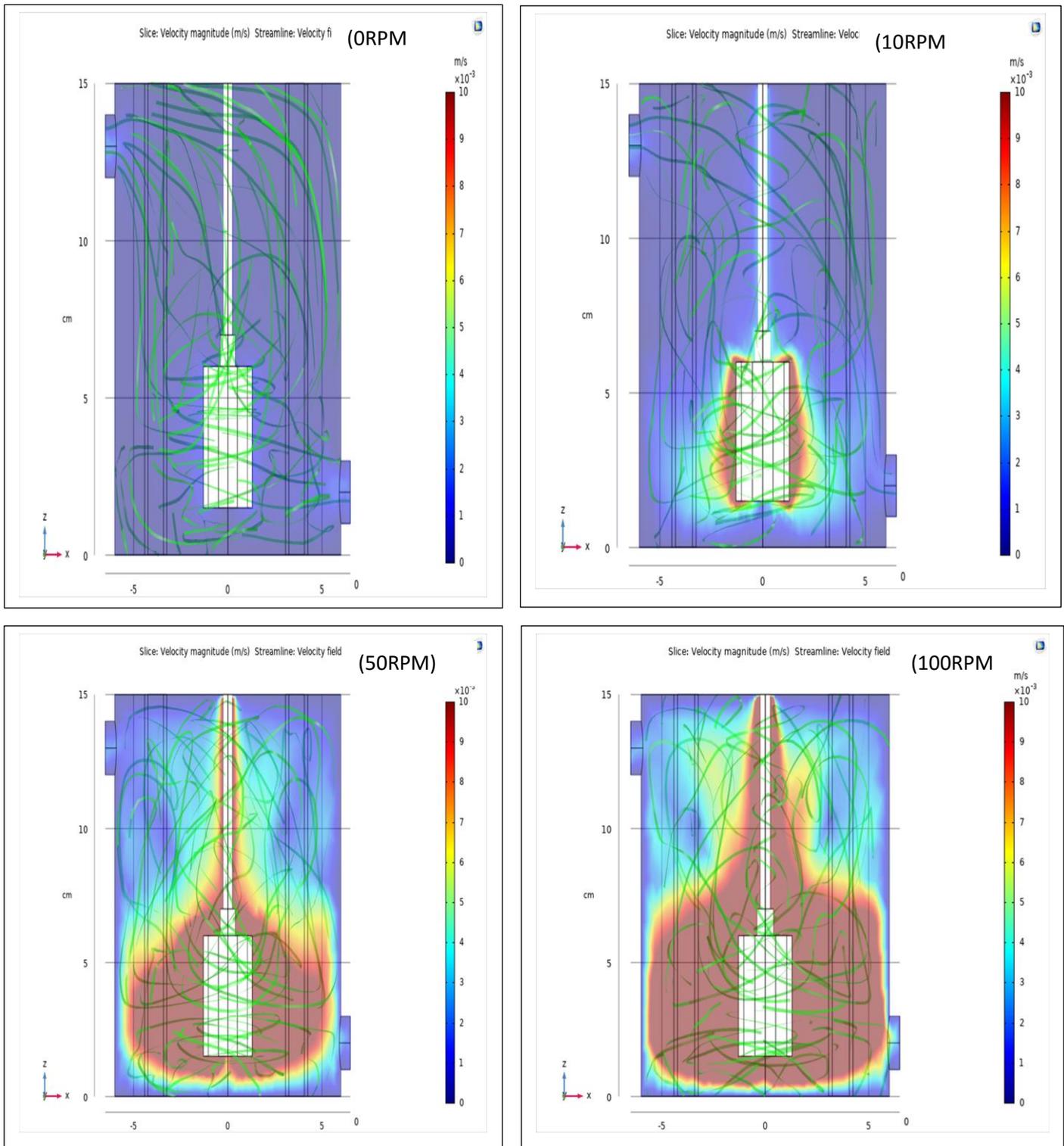


Figure (4.4) Velocity distribution in the EC reactor at applied voltages of 0,10,50 and 100 rpm V.

4.5 Coagulants Distribution

Figure (4.5) shows the transport of the produced ions(Al^{+3}) from anode as result of corrosion towards cathode. Near the cathode is OH^- transferred by diffusion, electro-migration and forced convection. The coagulants production concentration increases with time as **Figure(4.5 and 4.6)** show. The figures below at applied voltage 3 V, HRT 30 min and rotational speed 10 rpm. The coagulants concentration production depends on operational conditions of the reactor like HRT, time, the applied voltage the rotating speed and the current density. The coagulants production starts increasing with time. **Figure (4.6)**. the chart below at the outlet of EC reactor which need time to produce the coagulants, the coagulants production increase with time as the rest of parameters fix.

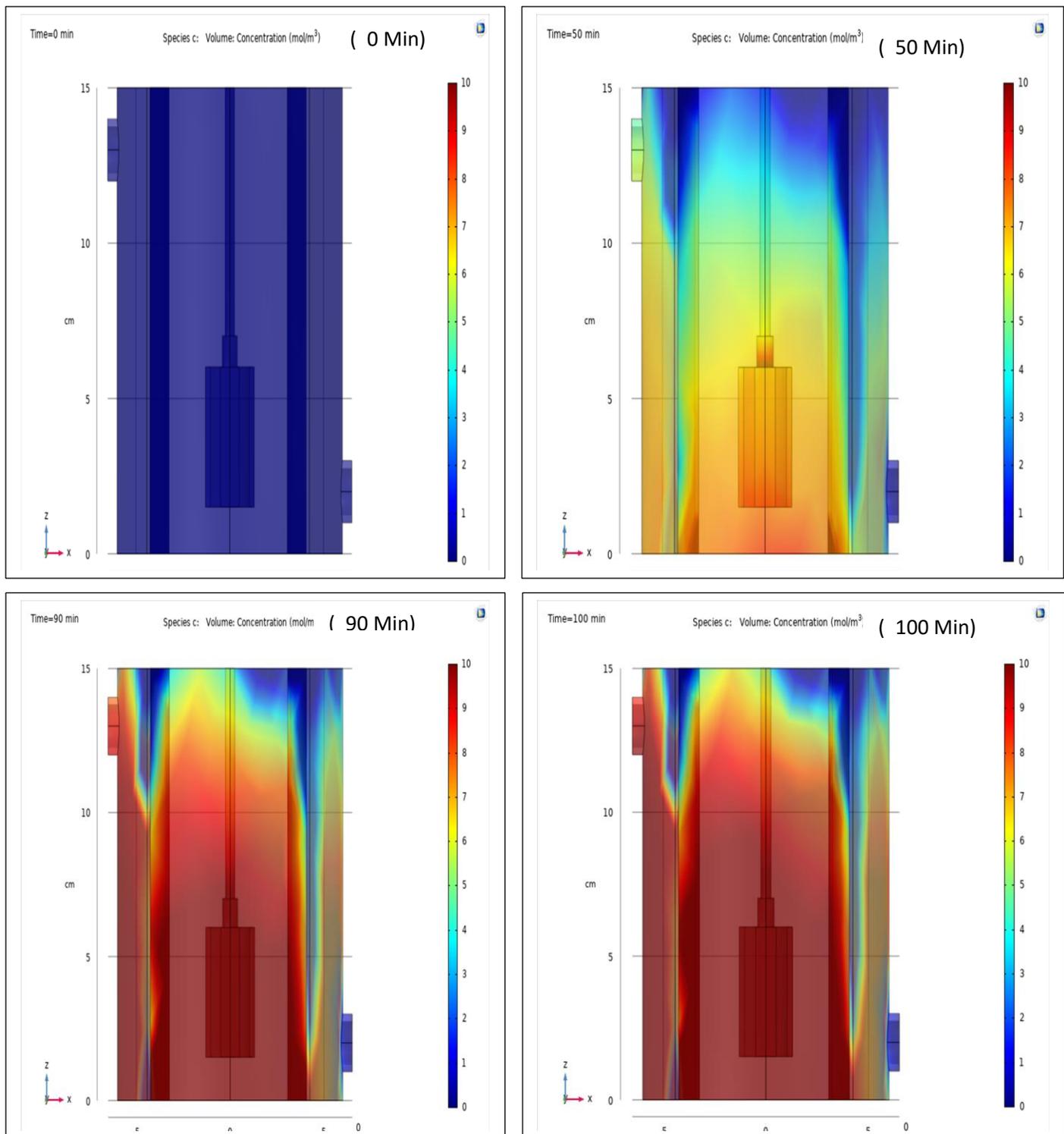


Figure (4.5) Coagulants distribution in the EC reactor at applied voltage of 3V, HRT of 30 Min. and 10rpm

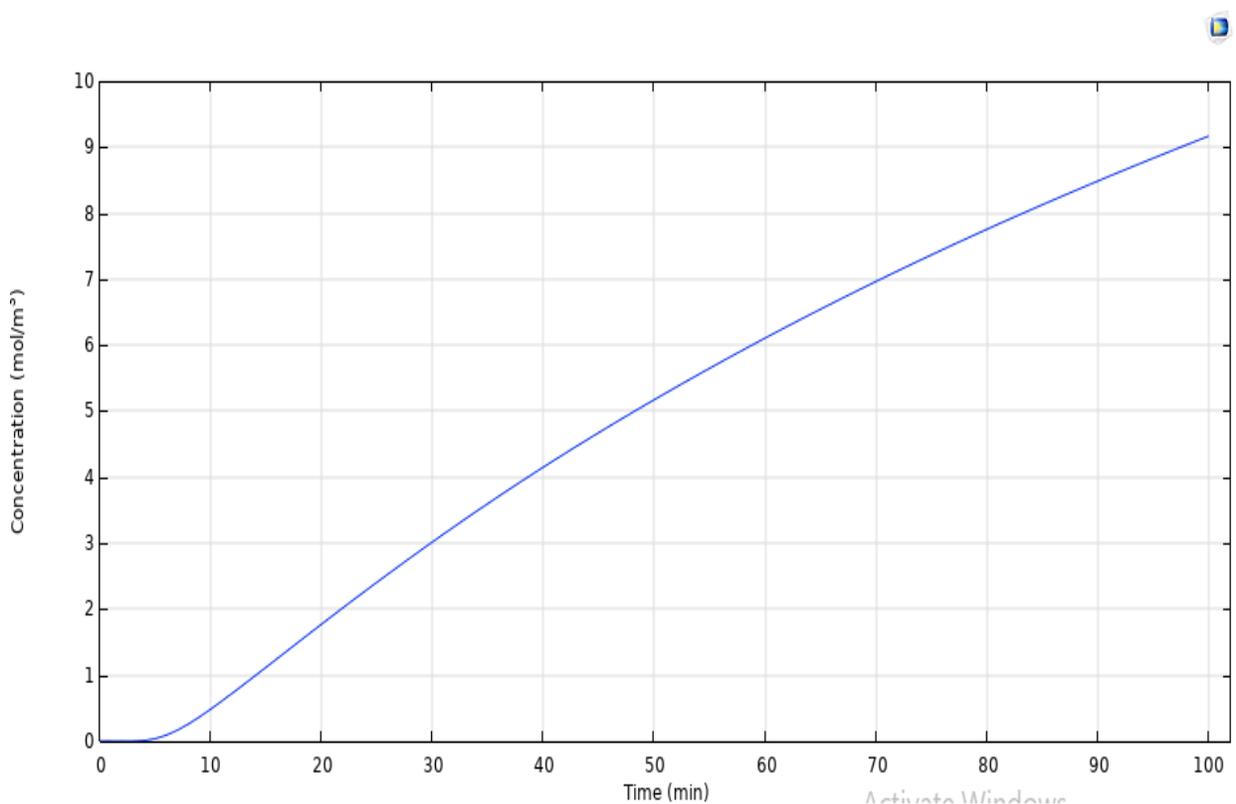


Figure (4.6) Coagulants concentrations at the outlet of reactor at applied voltage of 3V, HRT of 30Min. and 10rpm .

4.6 Lead Concentration Distribution

The lead concentration starts reducing near the anode where the coagulants are being produced, by rotating the anode, the lead concentration decreases in the rest of the reactor except at the corner of the reactor, and the bottom corner since they are nearest to the anode. The top corner still has the maximum concentration due to the distance from the anode. As time passes, the lead concentration decreases until 0.2 mol/M^3 after 100 min. at the outlet of the reactor, **Figure(4.7a and b)**. The lead concentration decreases with time as the coagulants concentration increases to reach 0.2 mol/M^3 at 100 min. **Figure (4.8)**, the lead concentration starts to decrease after 10 min as the coagulants concentration increases and keeps decreasing with time by making other parameters fixed.

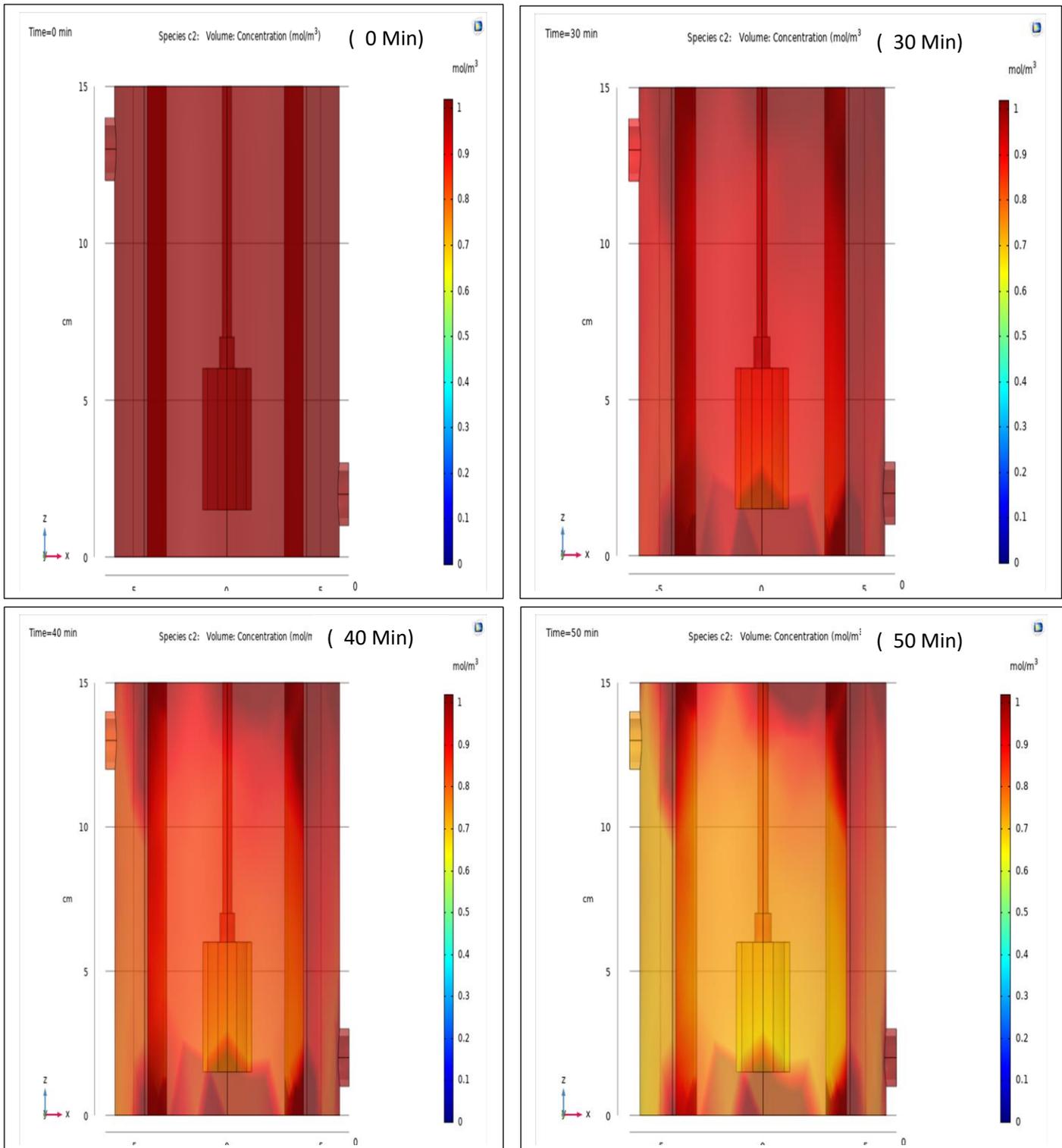


Figure (4.7a) Lead distribution in the EC reactor at applied voltage 3V,HRT 30Min and 10rpm.

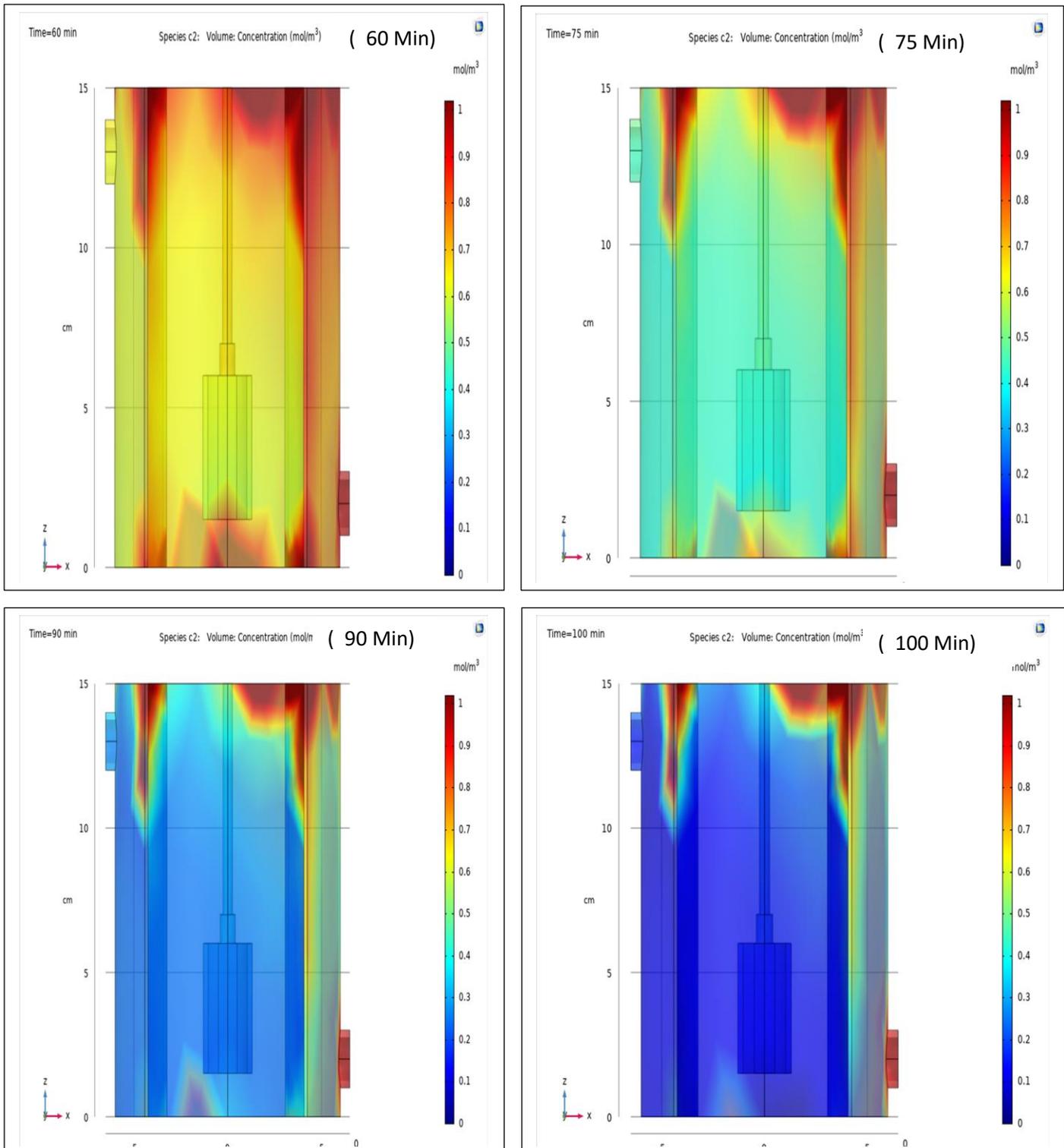


Figure (4.7b) Lead distribution in the EC reactor at applied voltage 3V,HRT 30Min. and 10rpm

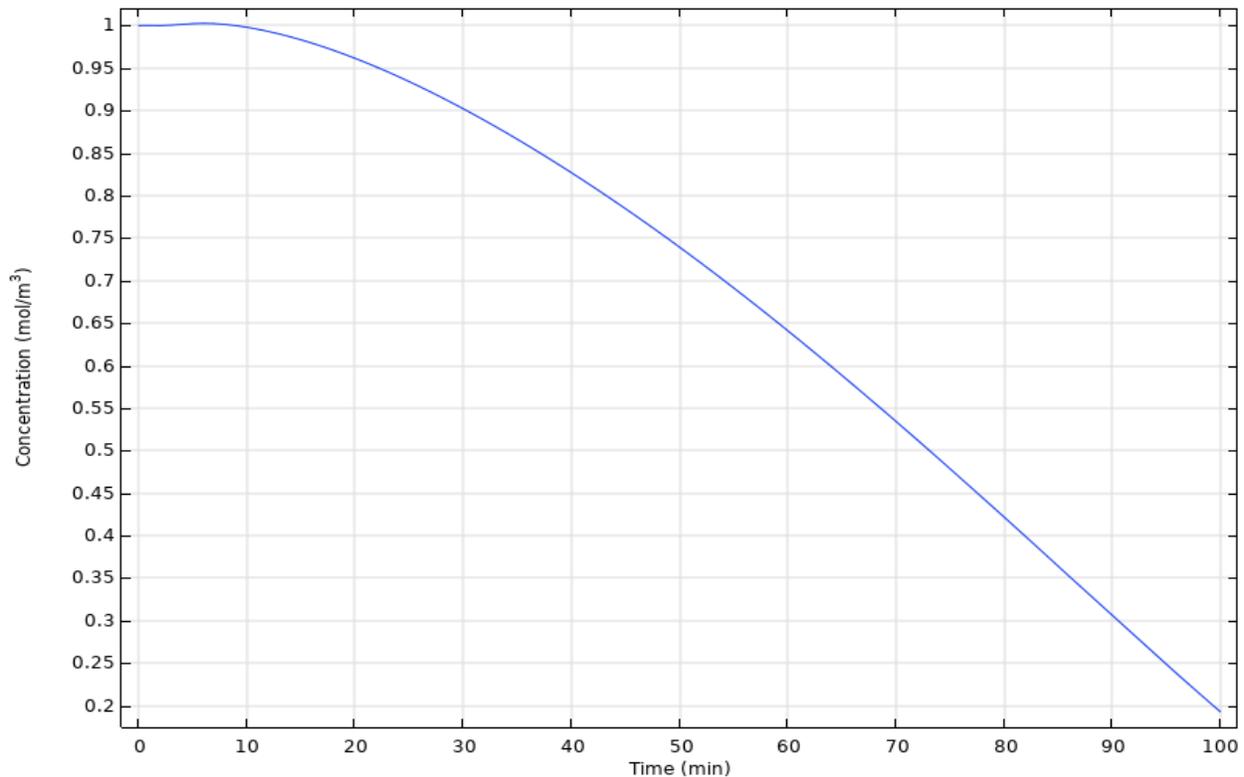


Figure (4.8) Lead concentrations at the outlet of EC reactor over time voltage 3V,HRT 30Min. and 10rpm .

4.7 Temperature Distribution

The initial temperature of the electrolyte is 293.15K, the temperature starts increasing around the anode due to it's the source of external power ,the temperature transfer to the rest of reactor gradually , Figures (4.9) shows the result of heat transfer equation solution. The temperature of EC reactor increases with time due to the applied voltage at the anode and the resistance of the martial the temperature of inlet stay same as it's the source of raw water and the top of the reactor because the big distance from the source of heat which is anode comparison with other parts of the reactor **Figure (4.10)** show Temperature at the outlet of EC reactor over time at voltage 3V,HRT 30Min. and 10rpm .

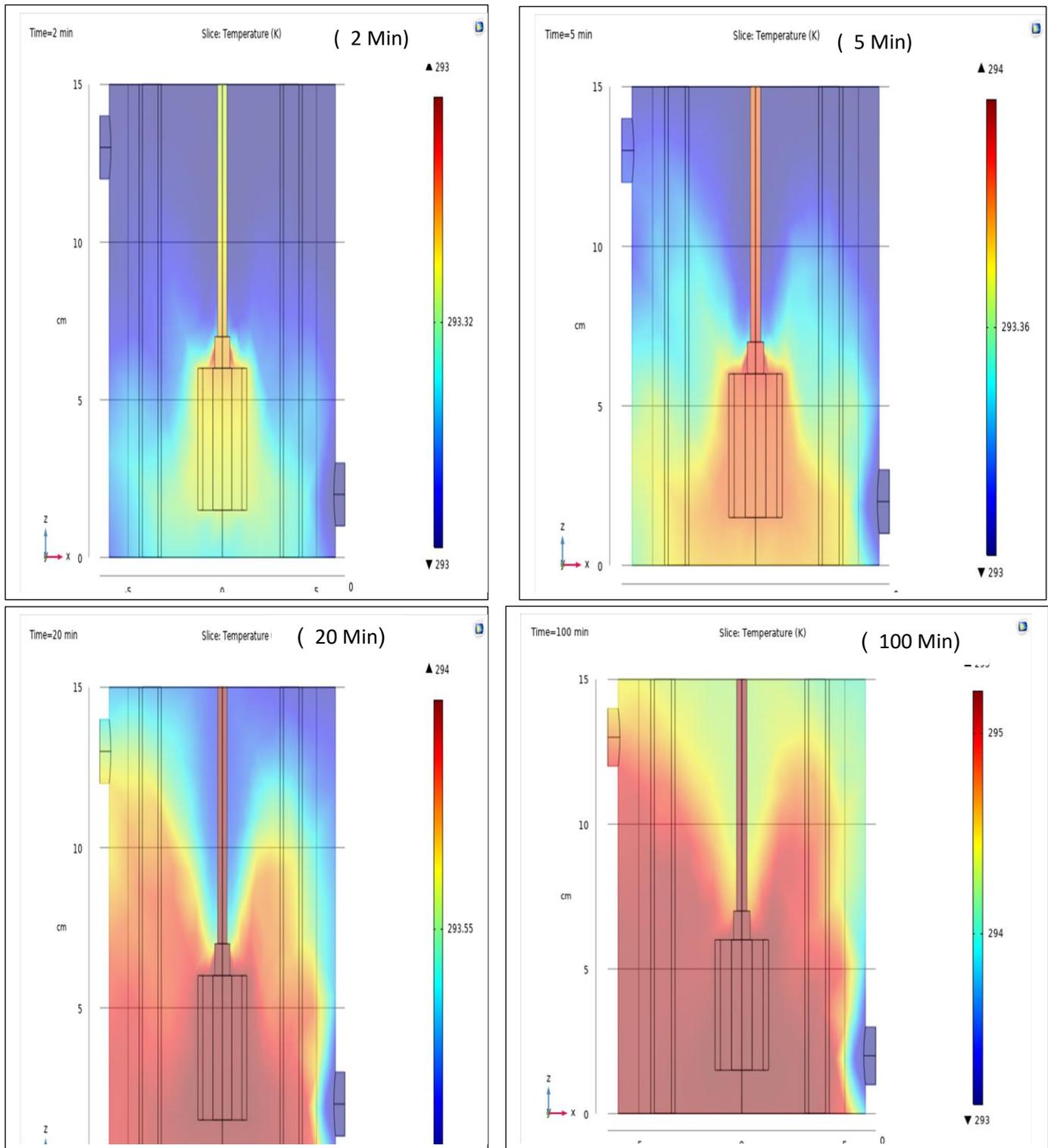


Figure (4.9) Temperature distribution in the EC reactor at applied voltage 3V,HRT 30Min. and 10rpm.

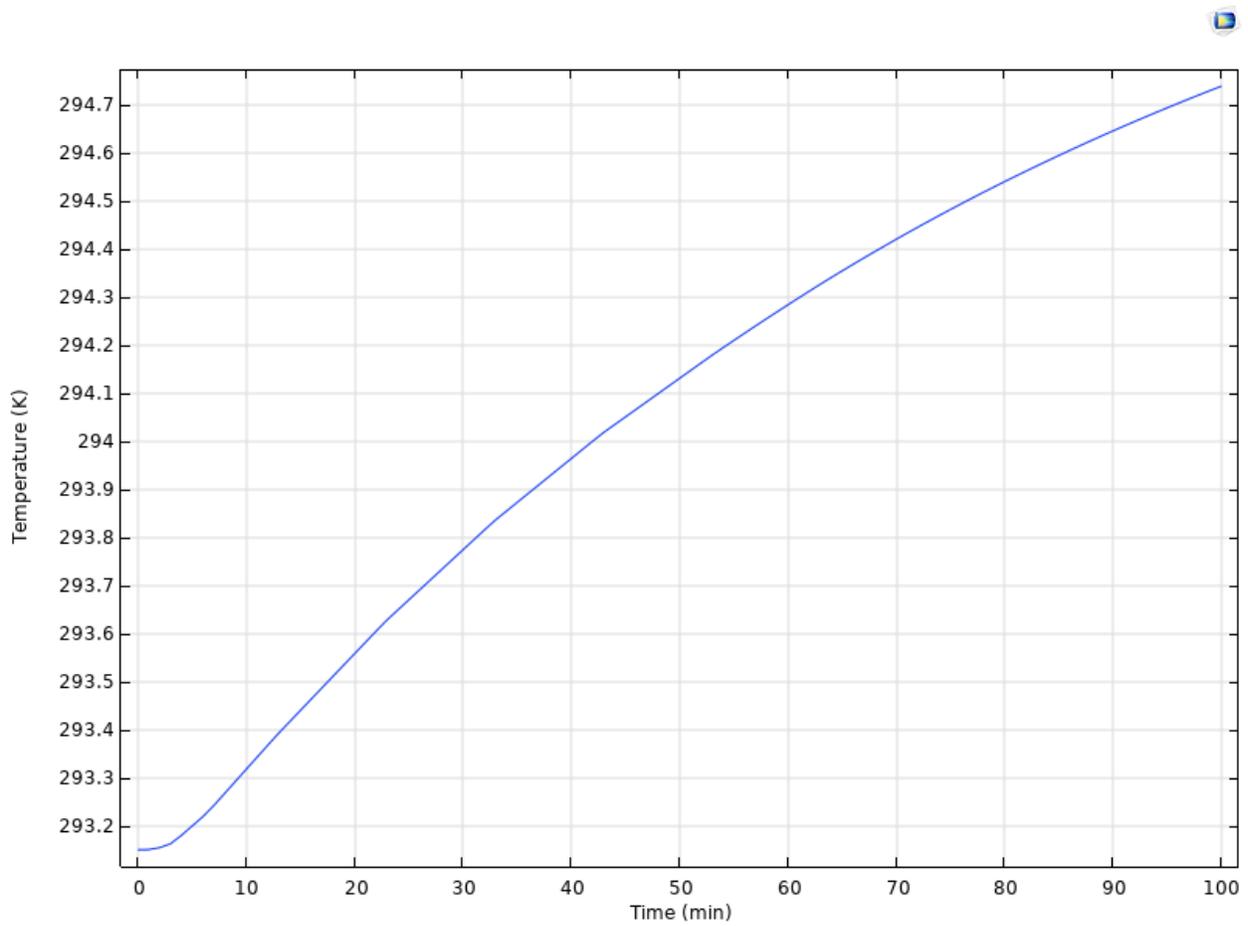


Figure (4.10) Temperature at the outlet of EC reactor over time voltage 3V, HRT 30Min. and 10rpm .

4.8 Effect Of Applied Voltage

4.8 .1 Effect Of Applied Voltage On Coagulants Production

Figures(4.11,12,13 and 14) show the transport of produced ions from anode towards cathode as a result of corroded anode to give Al^{+3} and ,near the cathode which the OH^- produced ,the transfer is doing by diffusion, electro-migration and forced convection ,the coagulants production concentration increase with time ,the figures below at applied voltage (1.5,3,6 and 10 V),HRT (30 min) and rotational speed (50 rpm).The coagulants concentration production depends on operational condition of the reactor like ,HRT, time , rotating speed current density(which they are not changing in this case) and applied voltage(which is changing in this case) .The coagulants production start increasing with time, starting increasing around anode to the rest of reactor. the chart below **Figure (4.15)** at the outlet of EC reactor which need time to produce the ions Al^{+3} at anode and OH^- at cathode and the reaction to produce the coagulants which is $Al(OH)_3$. **Figure (4.15)** shows the coagulants production with different applied voltage at outlet of reactor the **coagulants production increase with increasing applied voltage Orthai et al(2009)**. The maximum coagulants concentration in the reactor is in the **Table (4.3)** below:

No.	Applied voltage (V)	Coagulants mol/M ³	Time (min.)
1	1.5	7.59	100
2	3	14.76	100
3	6	27.5	100
4	10	41.18	100

TABLE (4.3) Coagulants concentration at different applied voltage .

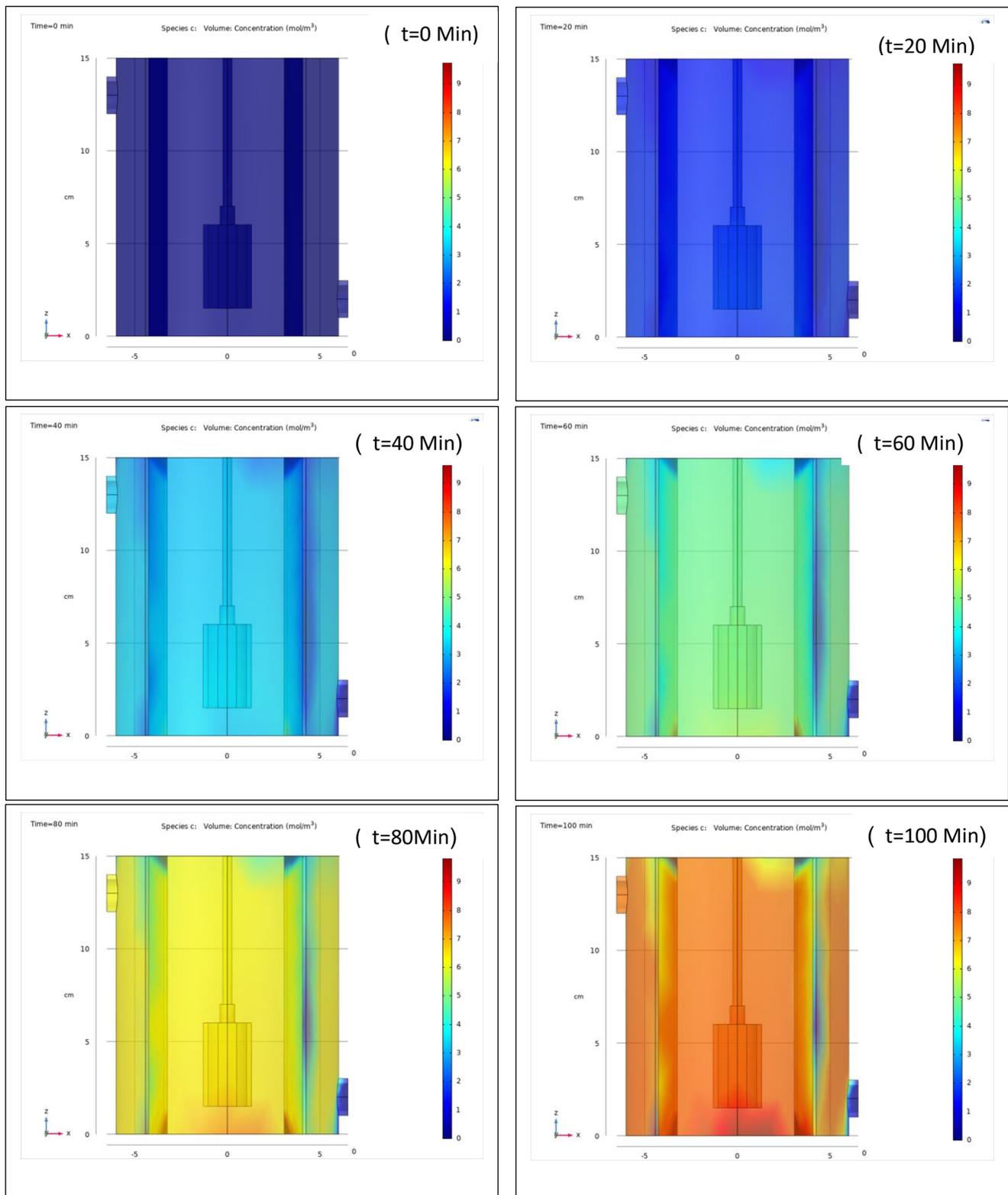


Figure (4.11) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=1.5V and rpm=50.

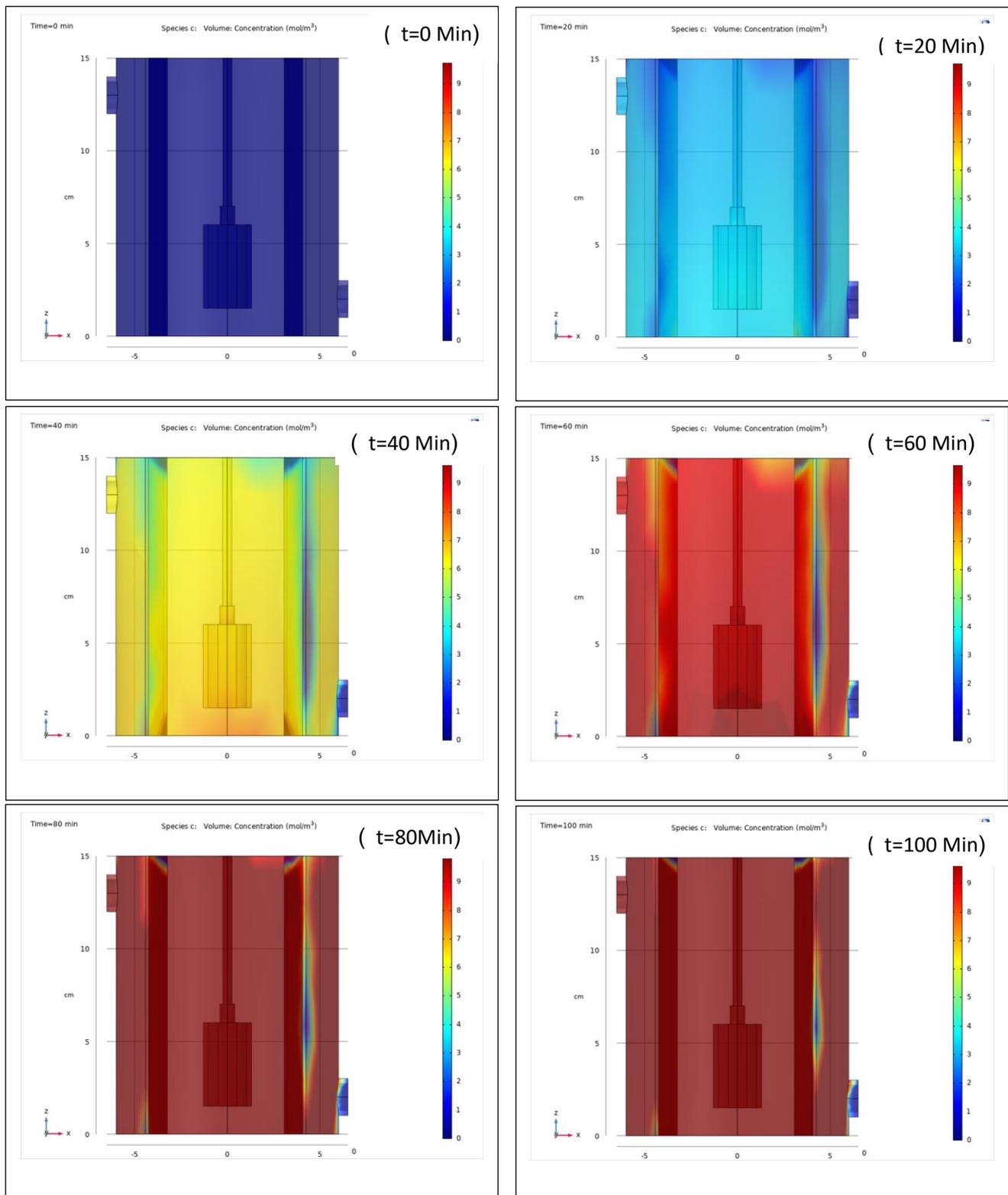


Figure (4.12) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=3V and rpm=50.

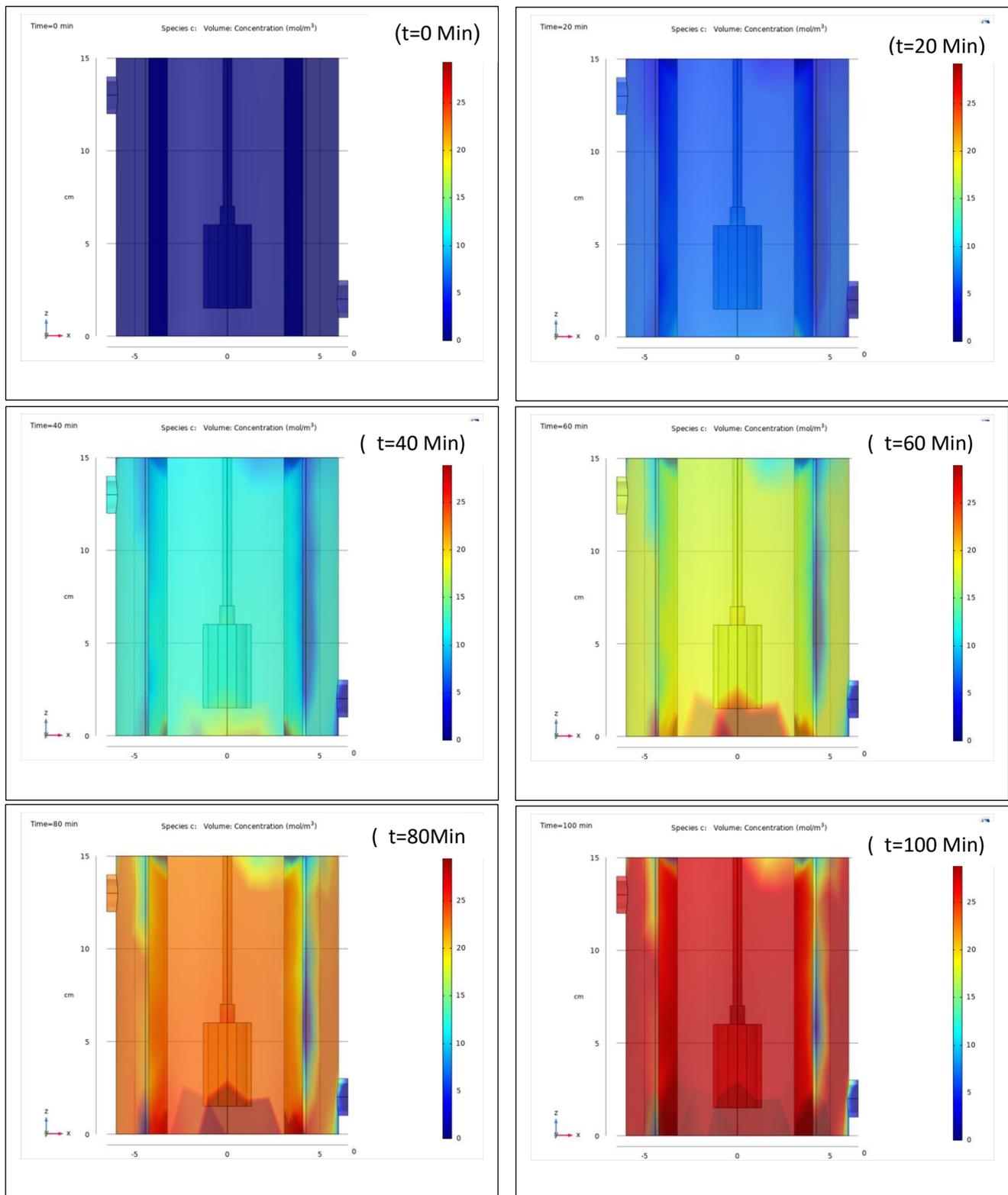


Figure (4.13) Distribution of coagulants in the EC reactor at HRT=30 min ,V=6V and rpm=50.

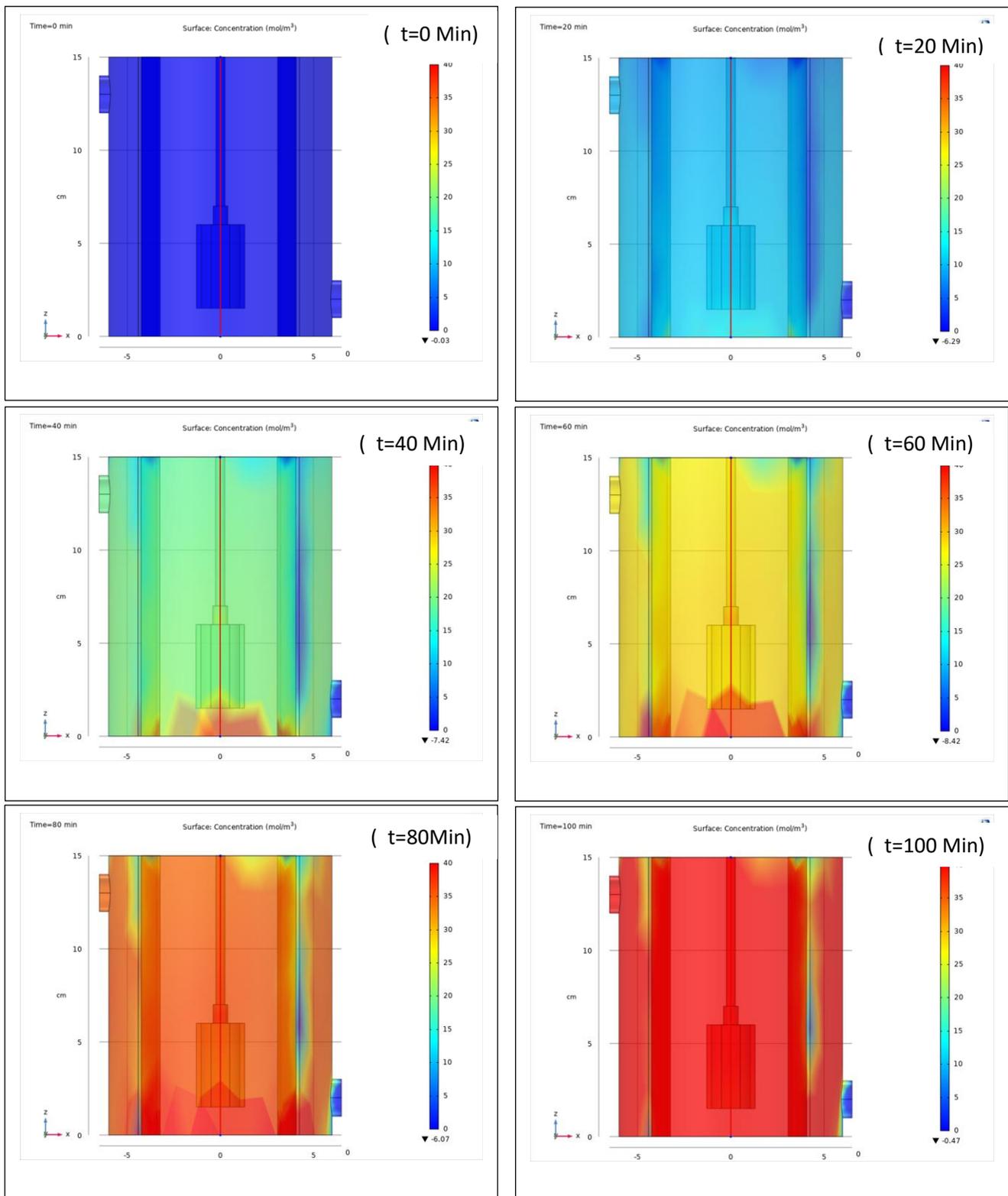


Figure (4.14) Distribution of Coagulants at V=10V, HRT=30 min and rpm=50.

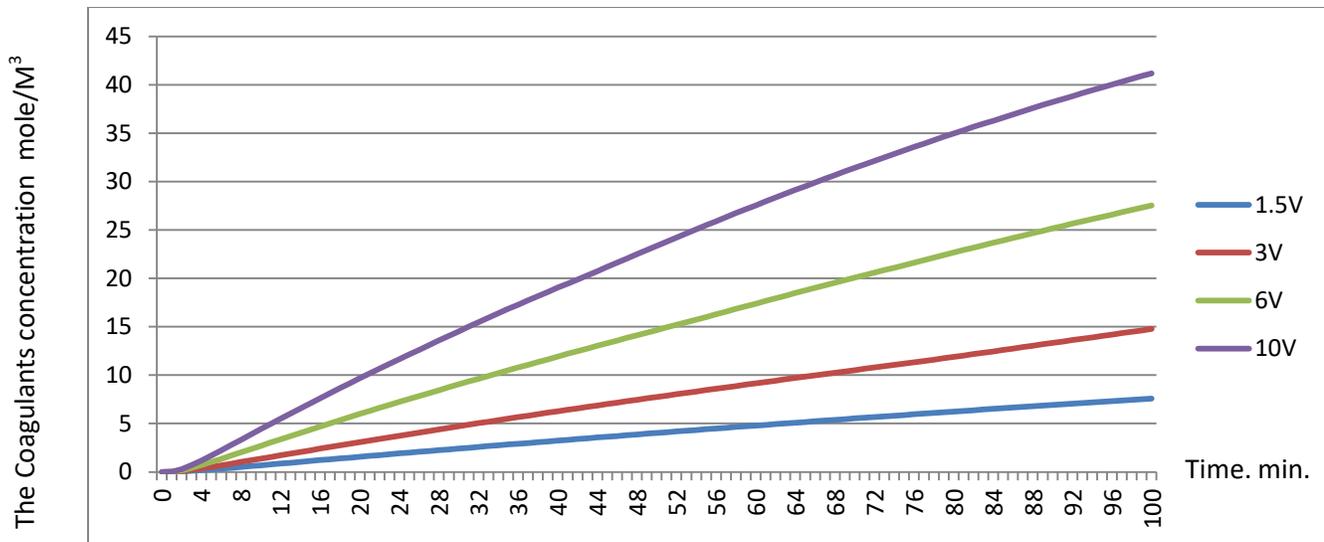


Figure (4.15) Distribution of Coagulants at 50 rpm and HRT=30 min.

4.8.2 Voltage Effect On Distribution Of Lead Concentration

Figures(4.16,17,18 and 19) show the lead concentration removal at different applied voltage (1.5,3,6 and 10V) while the other parameters are same(HRT 30min.,rpm 50) which starts reduce near the anode where the coagulants starts produced ,then the lead concentration decrease for the rest of reactor except the corner of reactor ,then the bottom corner which they are nearest to the anode the lead start disappear while the top corner still has the maximum concentration due to the distance from the anode, **Figure(4.20)** shows the decreasing of lead at outlet of reactor with increasing applied voltage at same time keep the other parameters fix .within the time the lead concentration decrease as **Table(4.4)** below:

No.	Applied voltage (V)	Lead concentration Mol/M ³	Time
1	1.5	0.173	100
2	3	0.001	82
3	6	0.006	57
4	10	0.006	44

TABLE (4.4) Lead concentrations at different applied voltage at same variables .

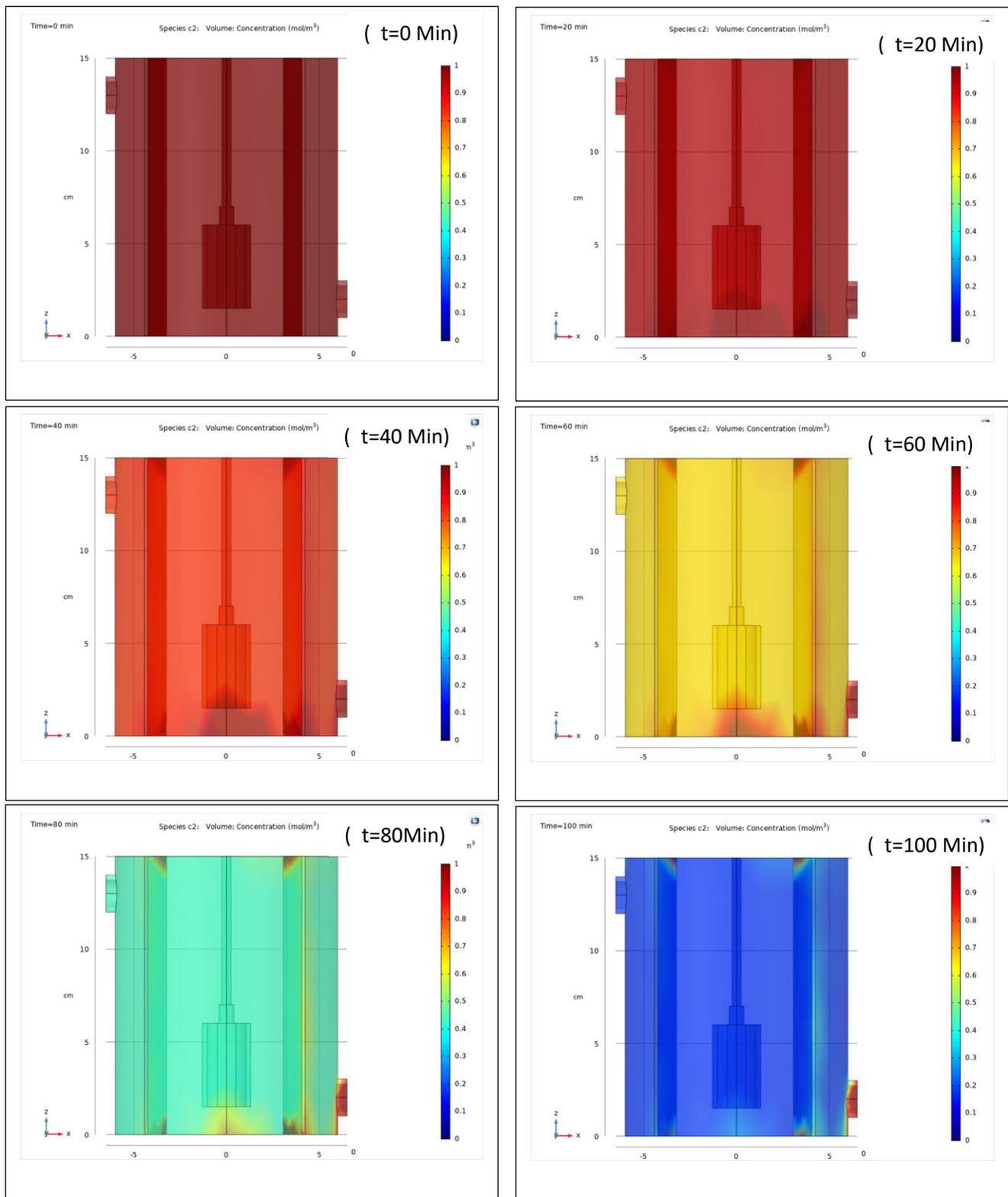


Figure (4.16) Lead distribution at HRT=30 min, V=1.5V and rpm=50.

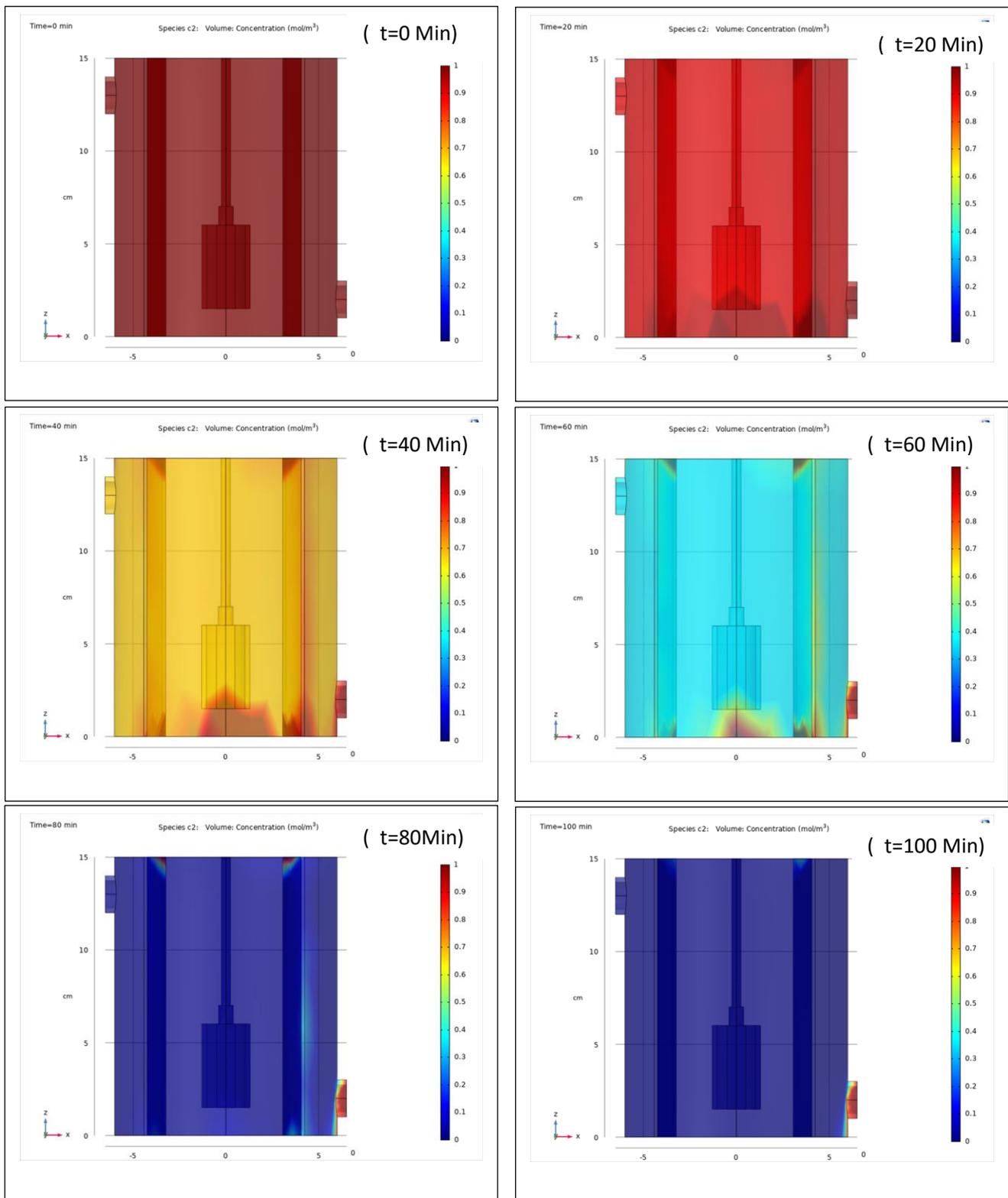


Figure (4.17) Lead distribution at HRT=30 min ,V=3V and rpm=50 .

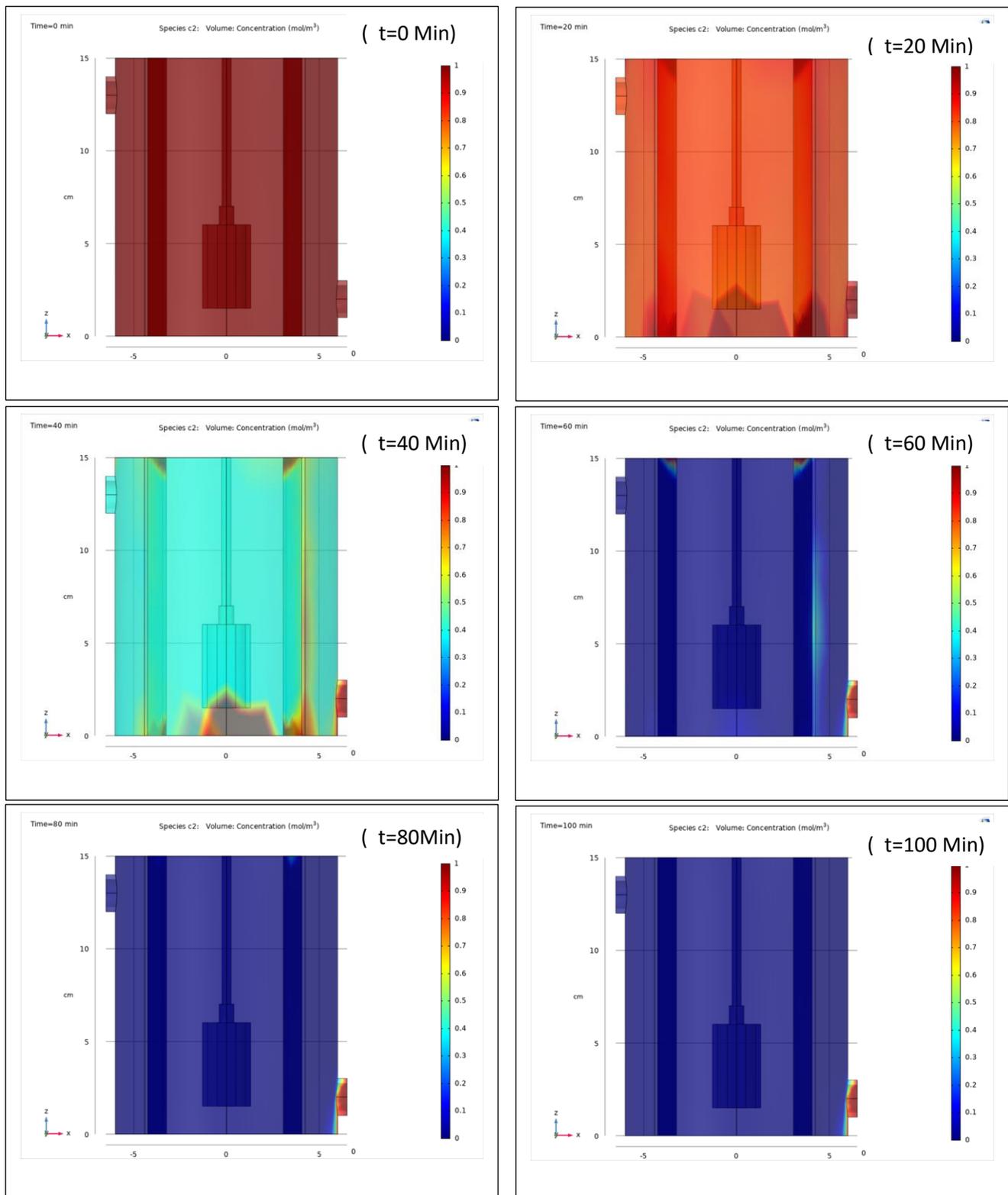


Figure (4.18) Lead distribution at HRT=30 min ,V=6V and rpm=50 .

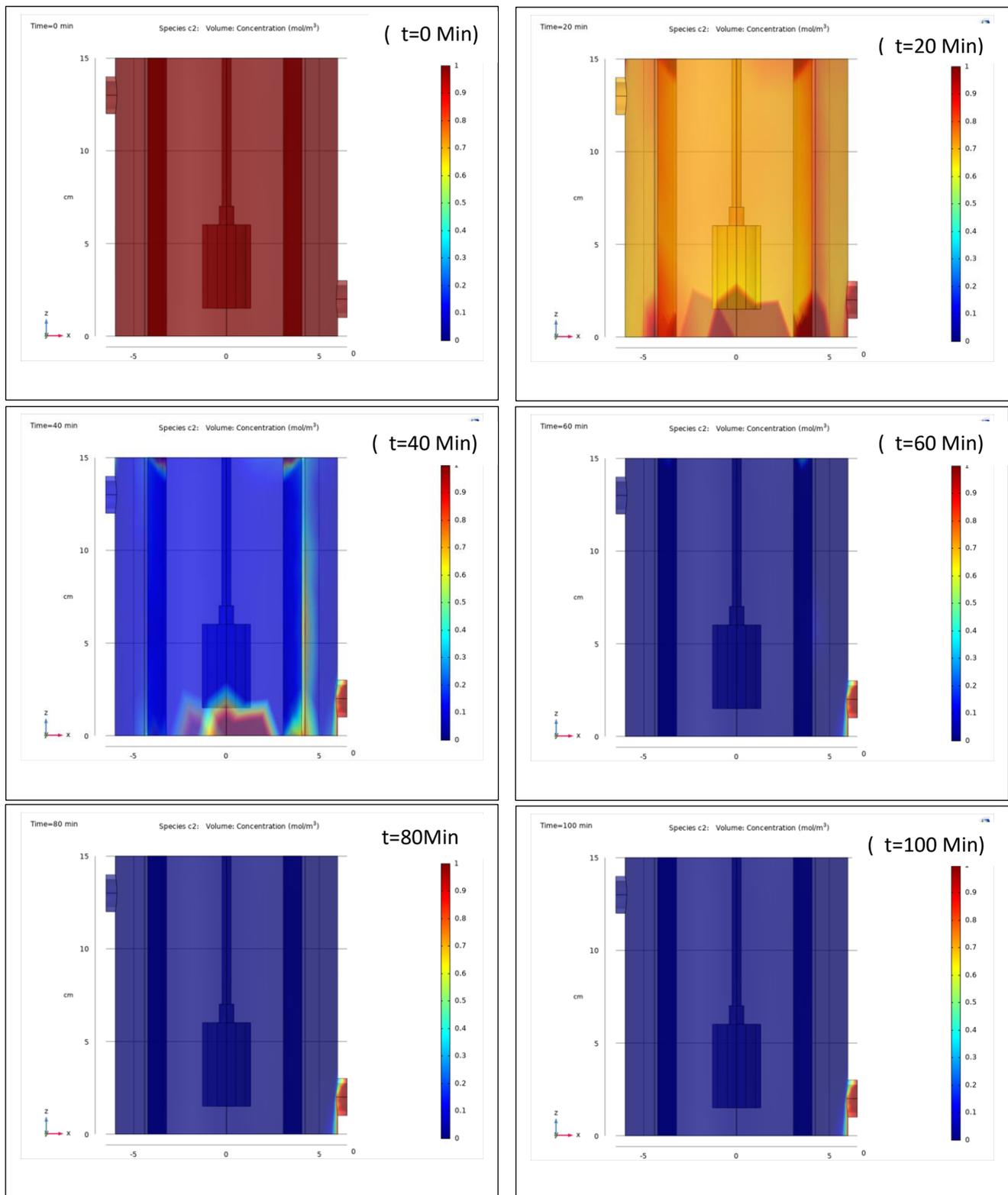


Figure (4.19) Lead distribution at HRT=30 min , V=10V and rpm=50 .

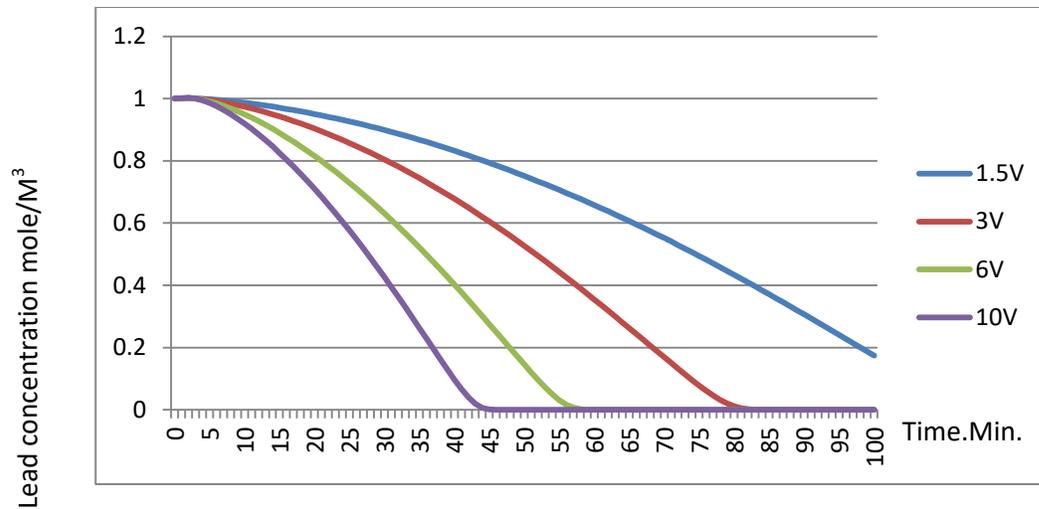


Figure (4.20) Lead distribution at)HRT=30 min and 50 rpm.

4.8.3 Effect Of Applied Voltage On Temperature Distribution

The initial temperature of the electrolyte is 293.15K ,the temperature starts increasing around the anode then, the temperature transfer to the rest of reactor gradually except the inlet because it's the source of raw material which its temperature 293.15K as result to the anode resistant to the current passing throw it , **Figures (21,22,23 and 24.4)** show the result of heat transfer equation solution which show the increasing in temperature with increase applied voltage. The temperature of EC reactor increases over the time due to the applied voltage on the anode and the resistance of the anode martial become stable after 40min. **Figure (4.25)**.show the temperature at the rector outlet at HRT30 and 50 rpm with different applied voltage (1.5,3,6 and 10 V).The temperature of reactor in **Table (4.5)** below after 100 min. :

No.	Applied voltage (V)	Temperature (K)
1	1.5	293.55
2	3	294.75
3	6	299.59
4	10	311.09

TABLE (4.5) Temperature at different applied voltage and same variables.

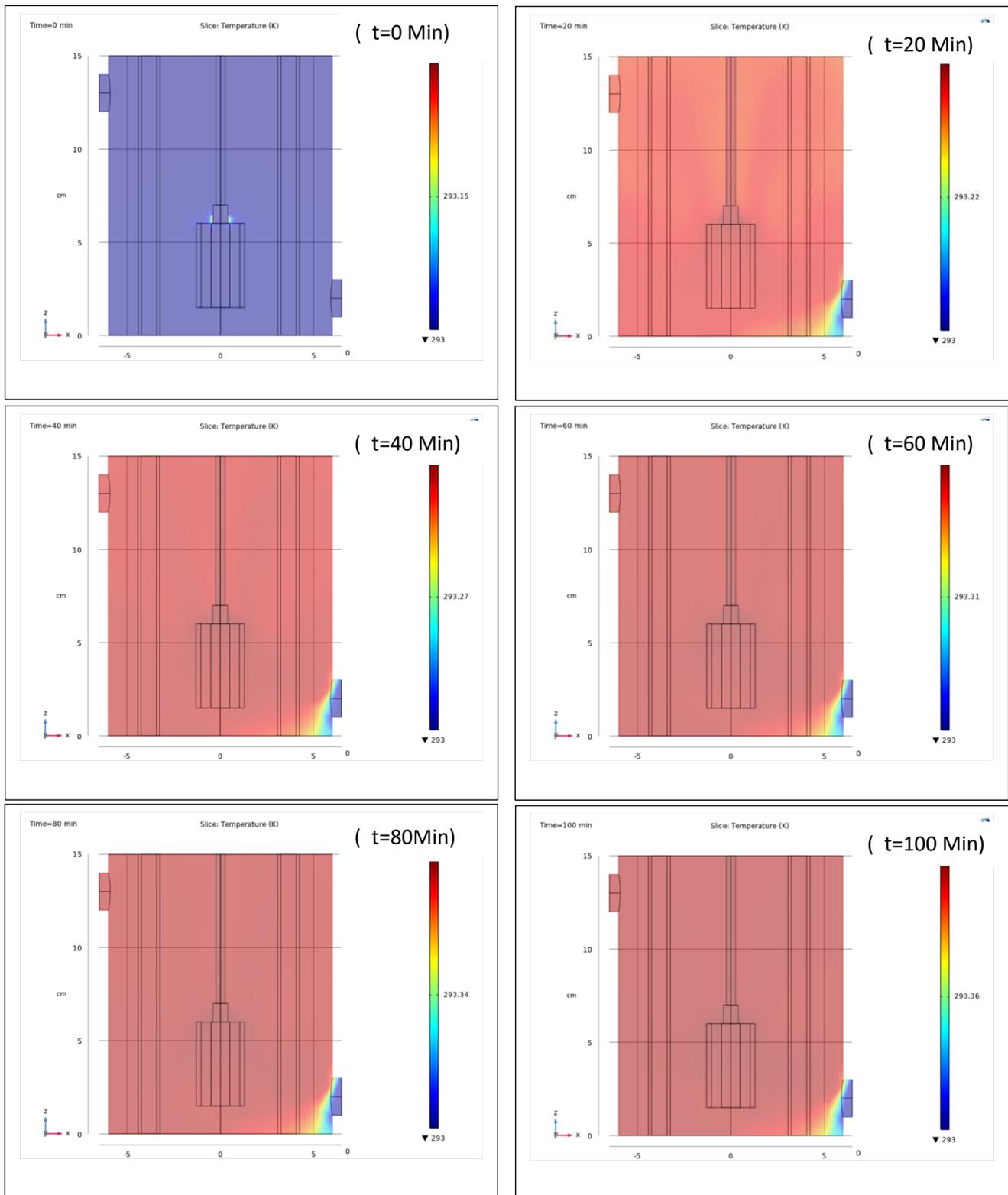


Figure (4.21) Distribution of temperature in the EC reactor at HRT=30 min ,V=1.5V and rpm=50.

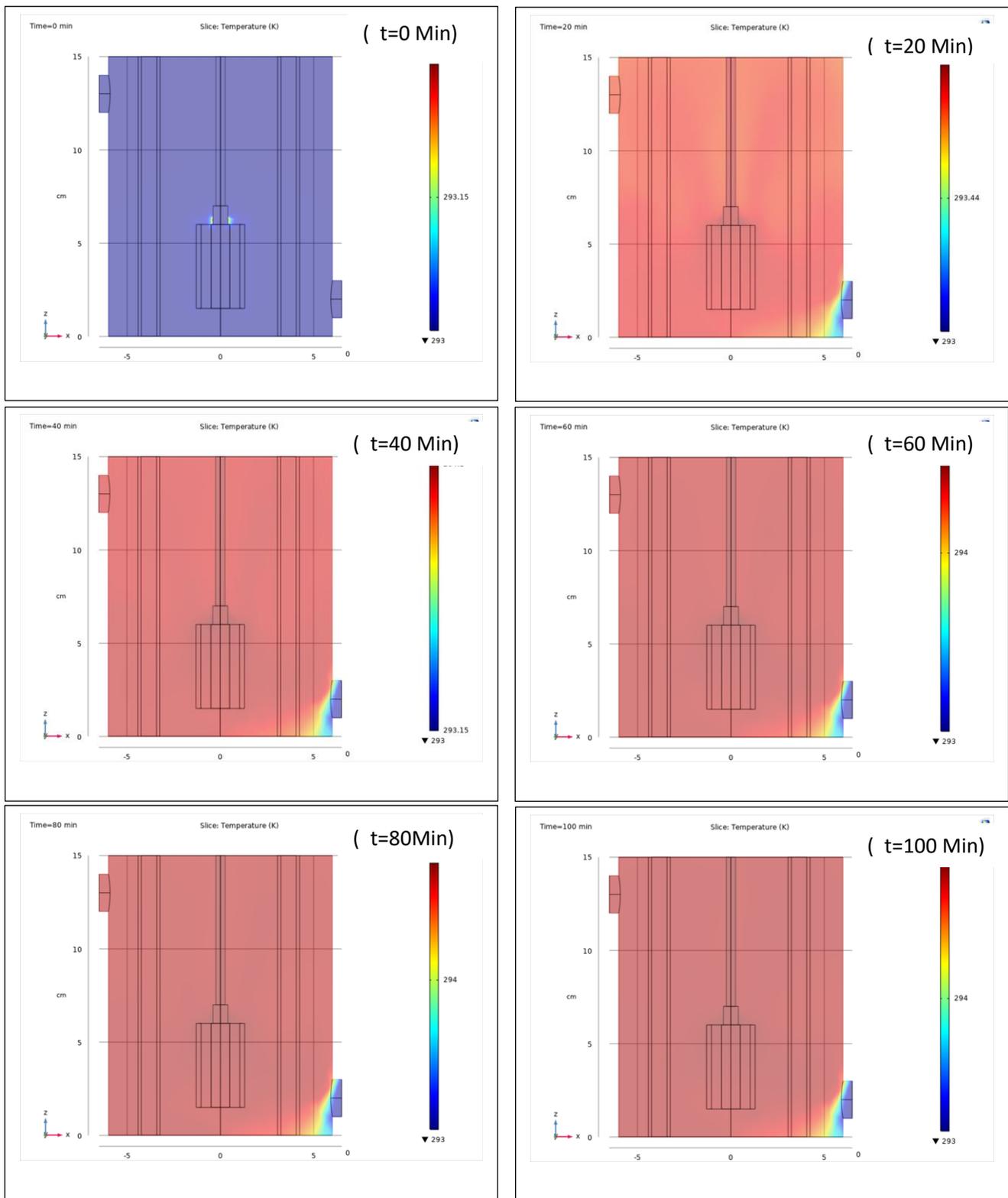


Figure (4.22) Distribution of temperature in the EC reactor at HRT=30 min ,V=3V and rpm=50 .

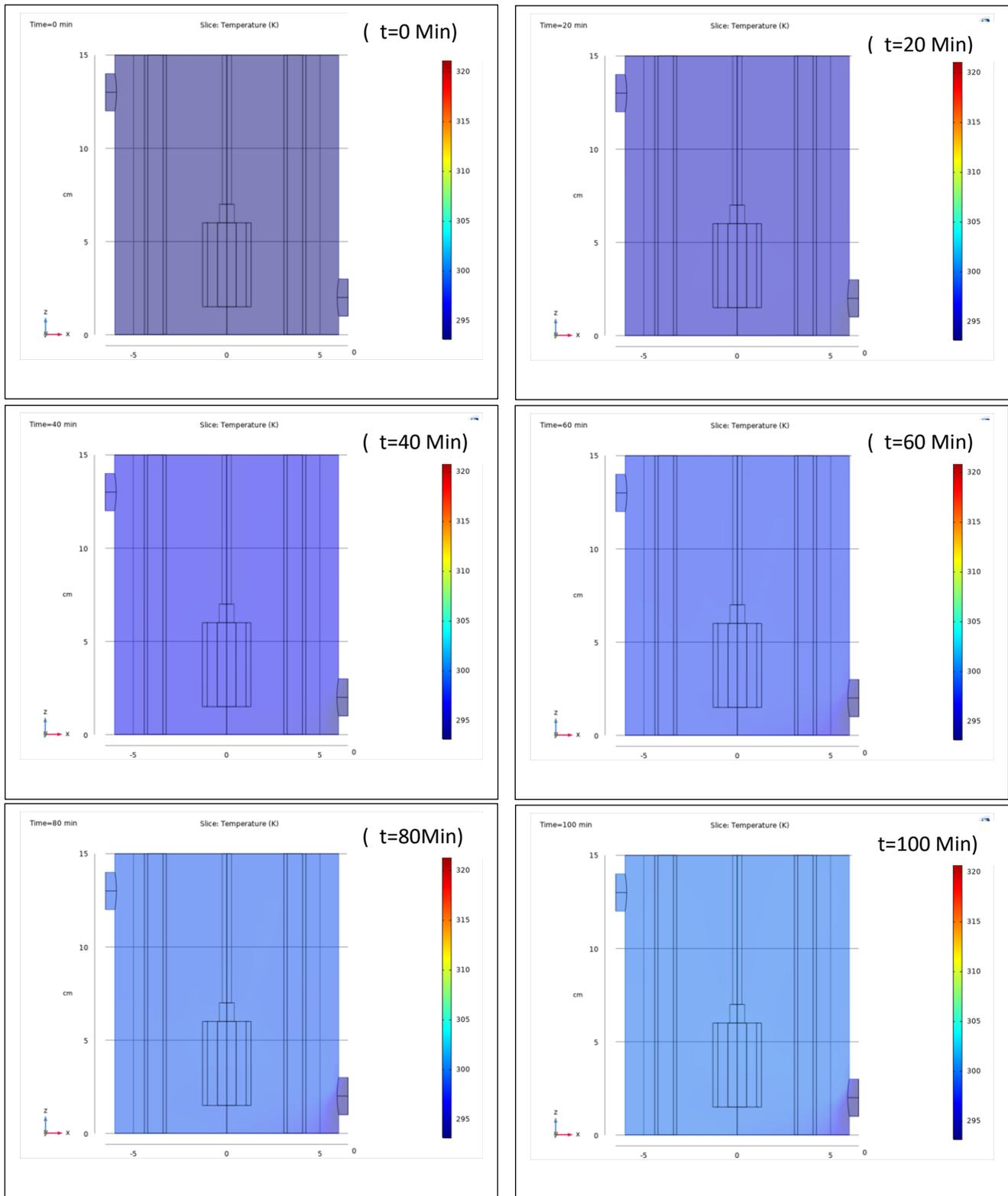


Figure (4.23) Distribution of temperature in the EC reactor at HRT=30 min ,V=6V and rpm=50 .

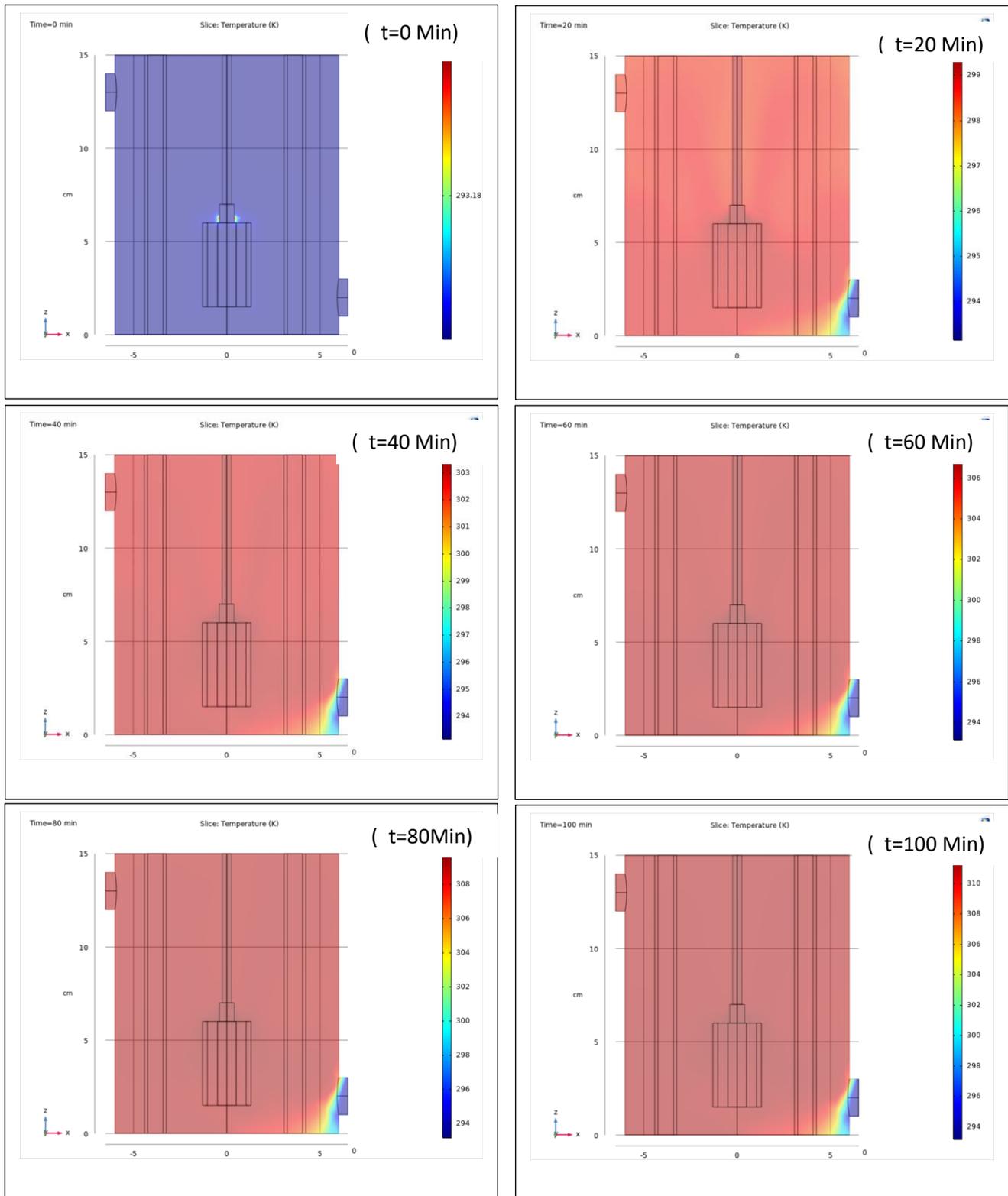


Figure (4.24) Distribution of heat in the EC reactor at HRT=30 min ,V=10V and rpm=50 .

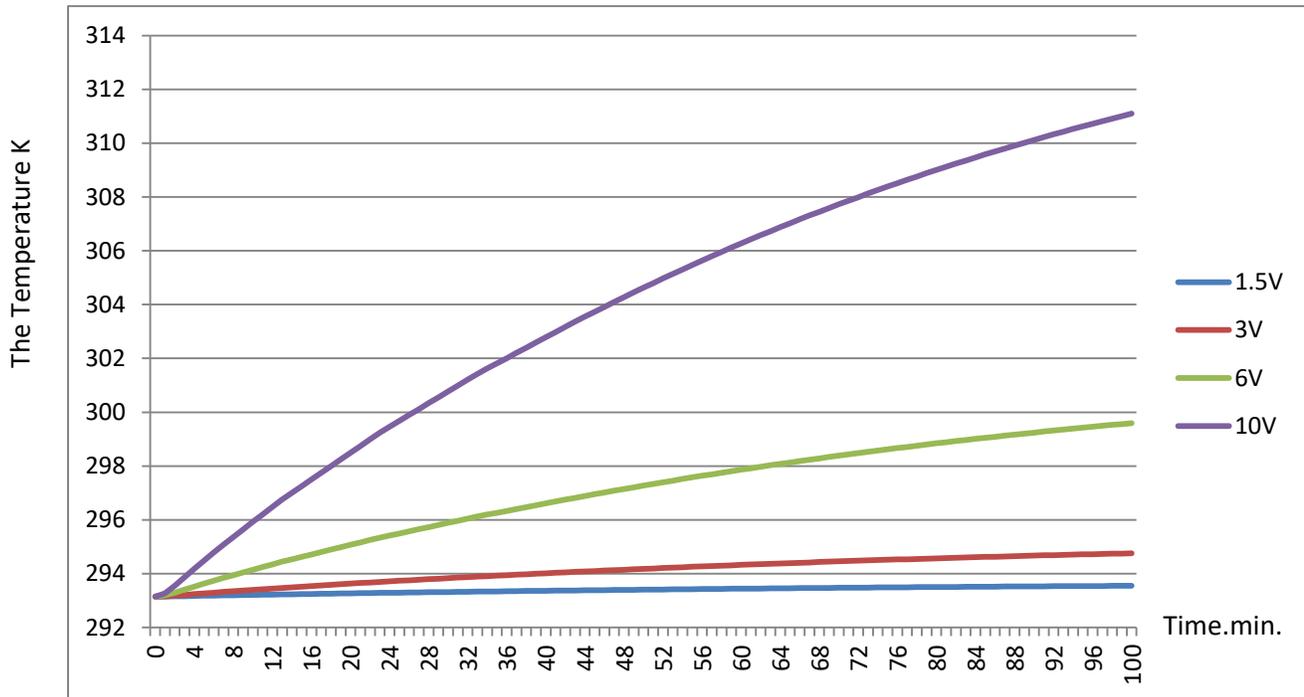


Figure (4.25) Distribution of temperature in the EC reactor at HRT=30 min and 50rpm .

4.9 Effect Of Rotating Speed

4.9.1 Effect Of Rotation Speed On The Coagulants Production

Increasing in the rotational speeds leads to increase the coagulants production which increases the pollutants removal by decreasing the time required to remove the pollutants **Helvio et al. Figures (4.26,27,28 and 29)** show the coagulants production distribution at different value of rotational speed(0,10,30,50and 100 rpm) while keep the other parameters fix(applied voltage 6V and HRT 30 min.) .When the anode doesn't rotate ,the coagulants production concentrate around the anode itself ,with time transfer towards the outlet of the reactor with flow rate

direction to the wall towards the outlet which is flow rate direction ,while the distribution in the reactor is not homogenous , when making the anode rotating the coagulants production increase ,the max value in 50 rpm more than this speed the coagulants production starts decrease due to the destabilization of coagulants **Huda(2020).**

Figure(4.30) shows the coagulants distribution with different rotational speed .

The coagulants distribution becomes more homogenous with speed rotational which make the removal process more efficient. The maximum value of the coagulants in the reactor in the **Table(4.6)** after 100 min , applied voltage is 6V and HRT=30 minutes, production of coagulants increase at the same time of the distribution.

No.	Rotational Speed (RPM)	Coagulants Mol/M ³
1	0	13.1
2	10	19.2
3	20	27.5
4	30	27

TABLE (4.6) Coagulants concentration at different rotational speed and same variables.

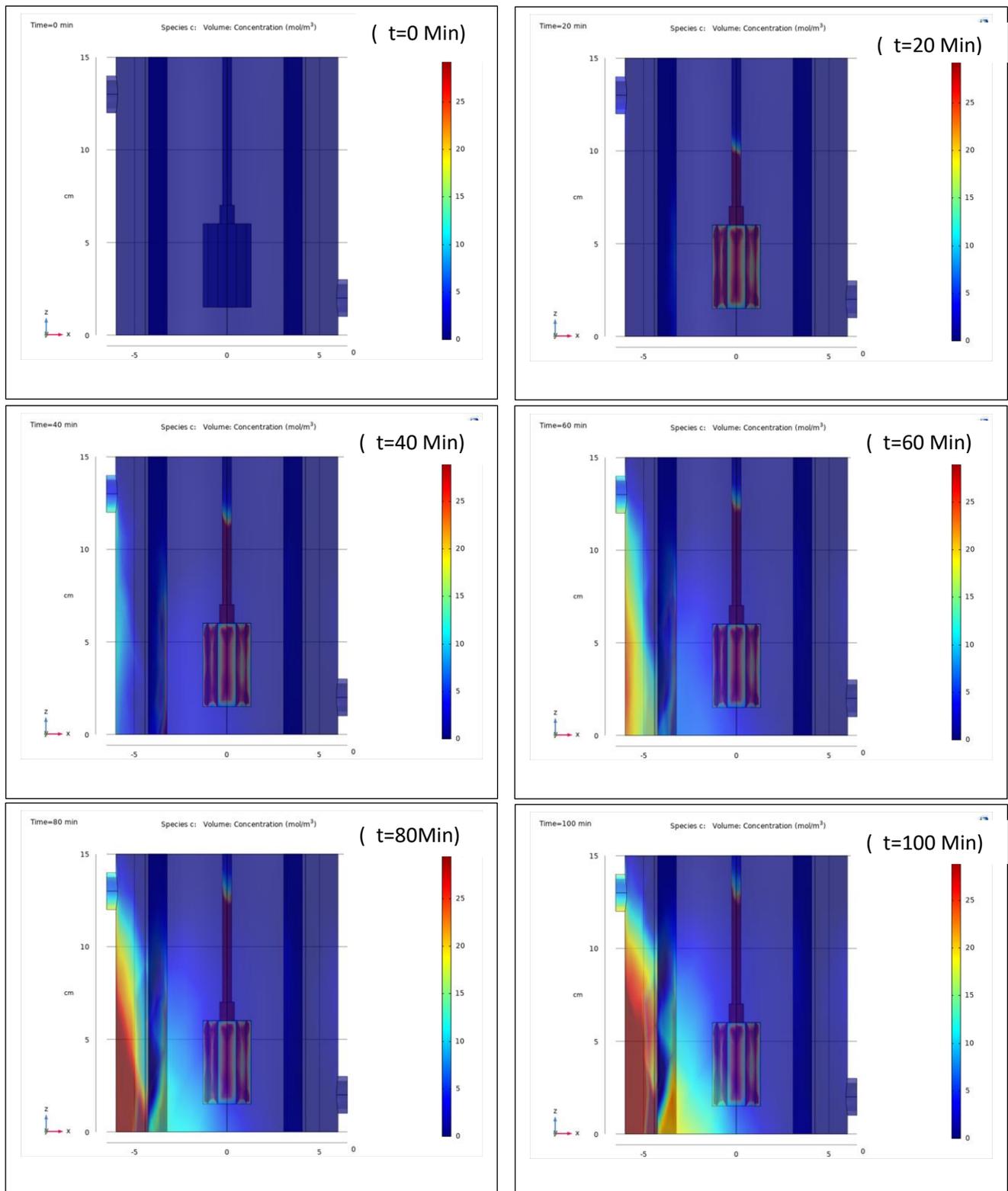


Figure (4.26) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=6V and rpm=0 .

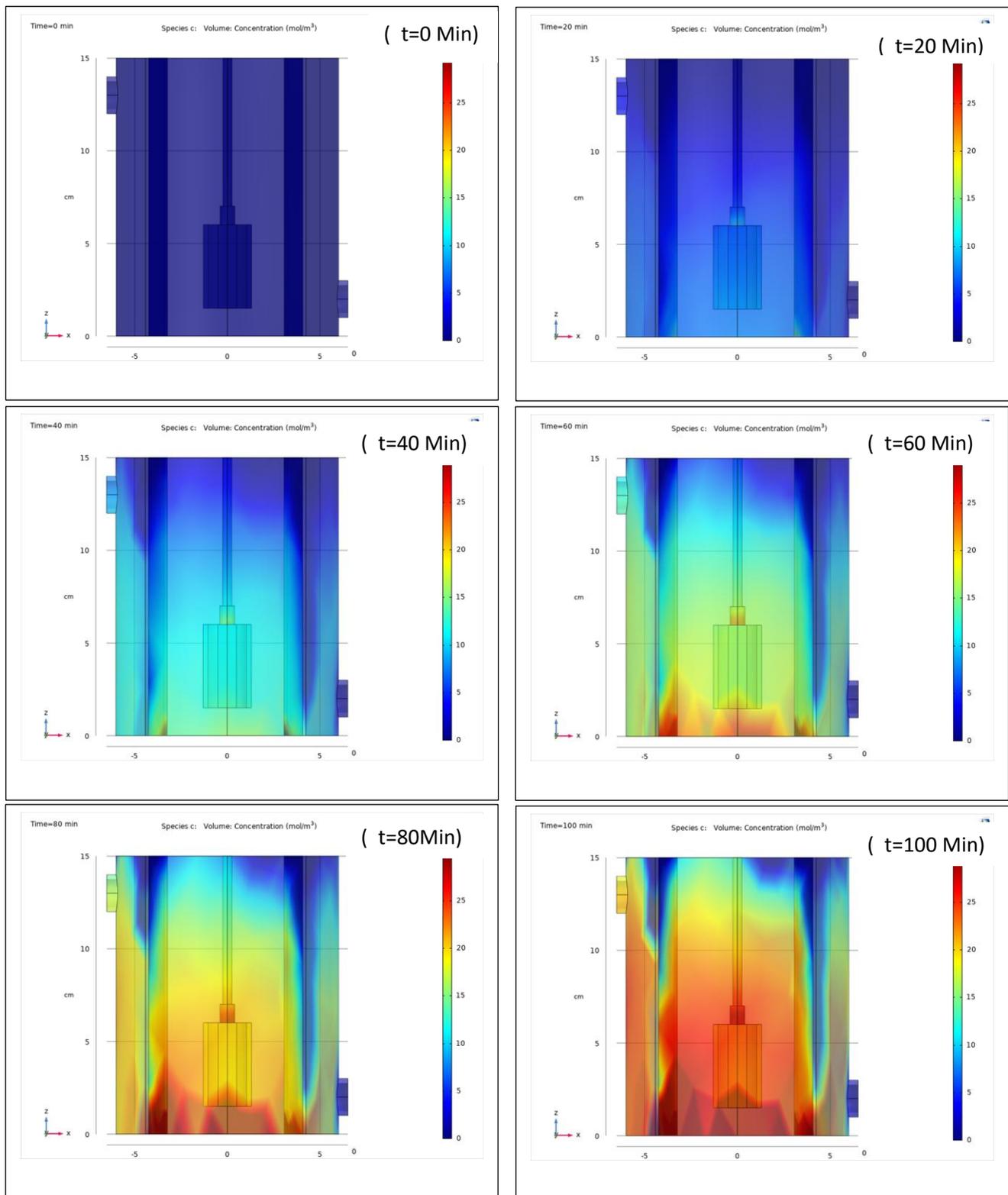


Figure (4.27) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=6V and rpm=10 .

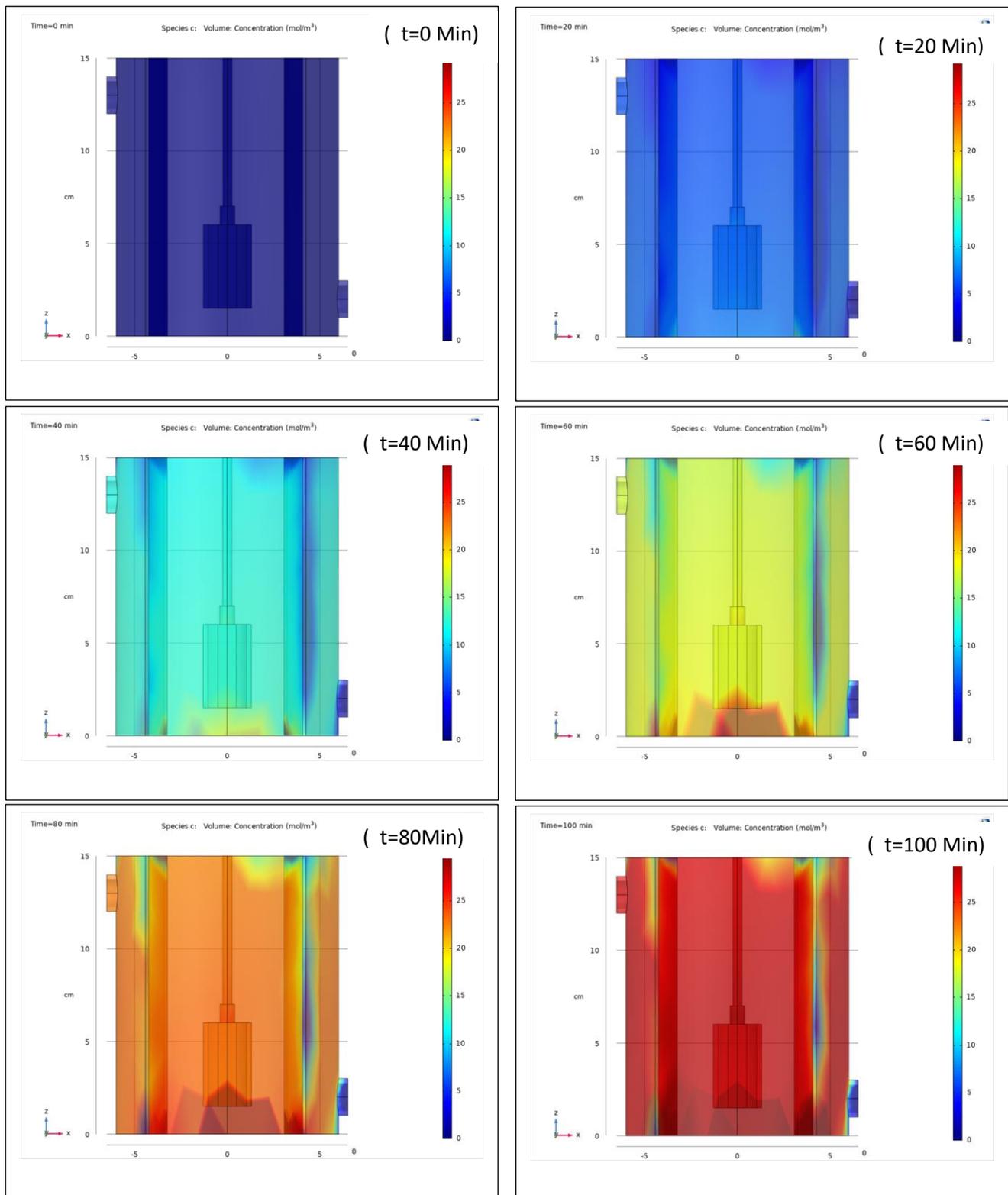


Figure (4.28) Distribution of coagulants in the EC reactor at HRT=30 min , $V=6V$ and rpm=50 .

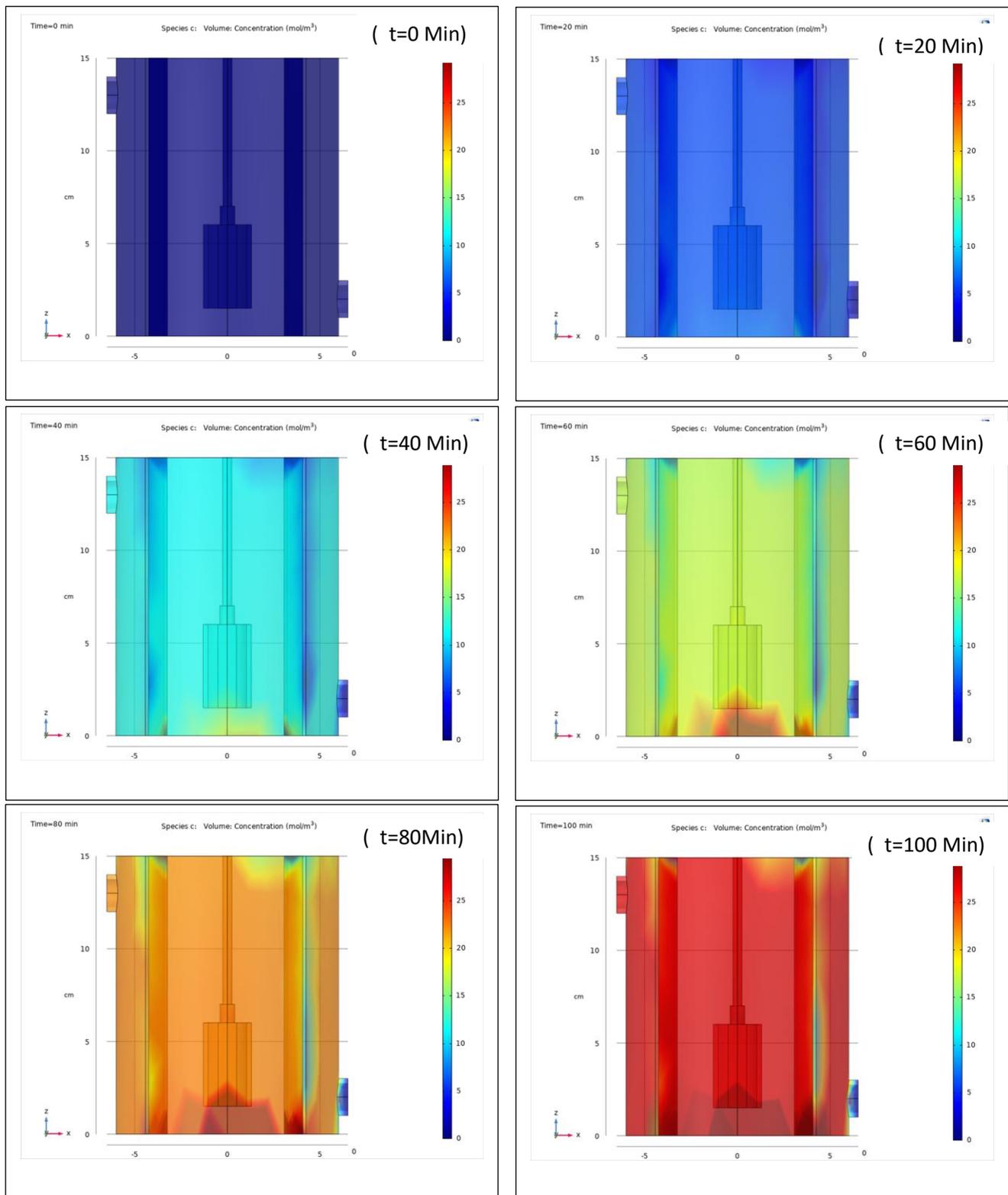


Figure (4.29) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=6V and rpm=100 .

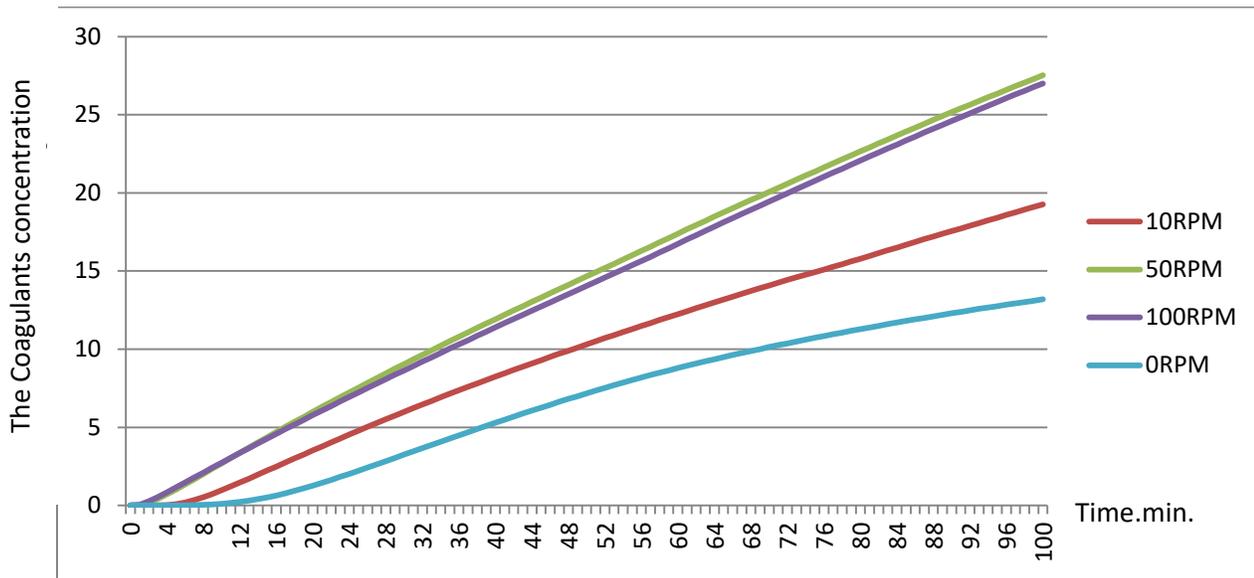


Figure (4.30) Distribution of Coagulants in the EC reactor at HRT=30 min ,V=6V.

4.9.2 Rotating Speed Influence On Lead Concentration Distribution

Rotating speed is enhancing the pollutants removal in EC reactor with limits, more than this limits the influence of this rotating become negative due to destabilization of the flocs, Helvio et al . Figure (4.31,32,33 and 34) shows the lead at different anode rotating speeds (0,10,50 and 100), at same time make other parameters constant ,applied voltage=6V,HRT=30 min and initial pollutant cementation is $1 \text{ mol} / \text{M}^3$.When using rpm zero the lead removal starts from anode ,then gradually to the outlet of EC reactor with flow rate direction, while the distribution of lead in the reactor not homogenous which is the same coagulants production concentration area, after 97 min of the process the out let lead from reactor is $0 \text{ mol}/\text{M}^3$. while the time required to remove the lead become shorter when the anode rotational speed become faster till 50 rpm more than this value (100 rpm) the time needed to remove the lead become longer with keeping the other parameters fix due to the decrease in coagulants production because the

destabilizing the flocs. **Figure (4.35)** describe the lead distribution at increasing the rotational speeds from 10,50 to 100 rpm, the lead distribution become homogenous and the time to remove the lead become shorter **Table(4.7)** state the time required to remove the lead with different rotational speed and keeping other parameters constant. That's mean the better rotational speed is 50 rpm.

No.	Rotational Speed (RPM)	Lead Concentration Mol/M ³	Time (Min.)
1	0	0	97
2	10	0	84
3	50	0	57
4	100	0	60

TABLE (4.7) Lead concentration at different rotational speed and same variables.

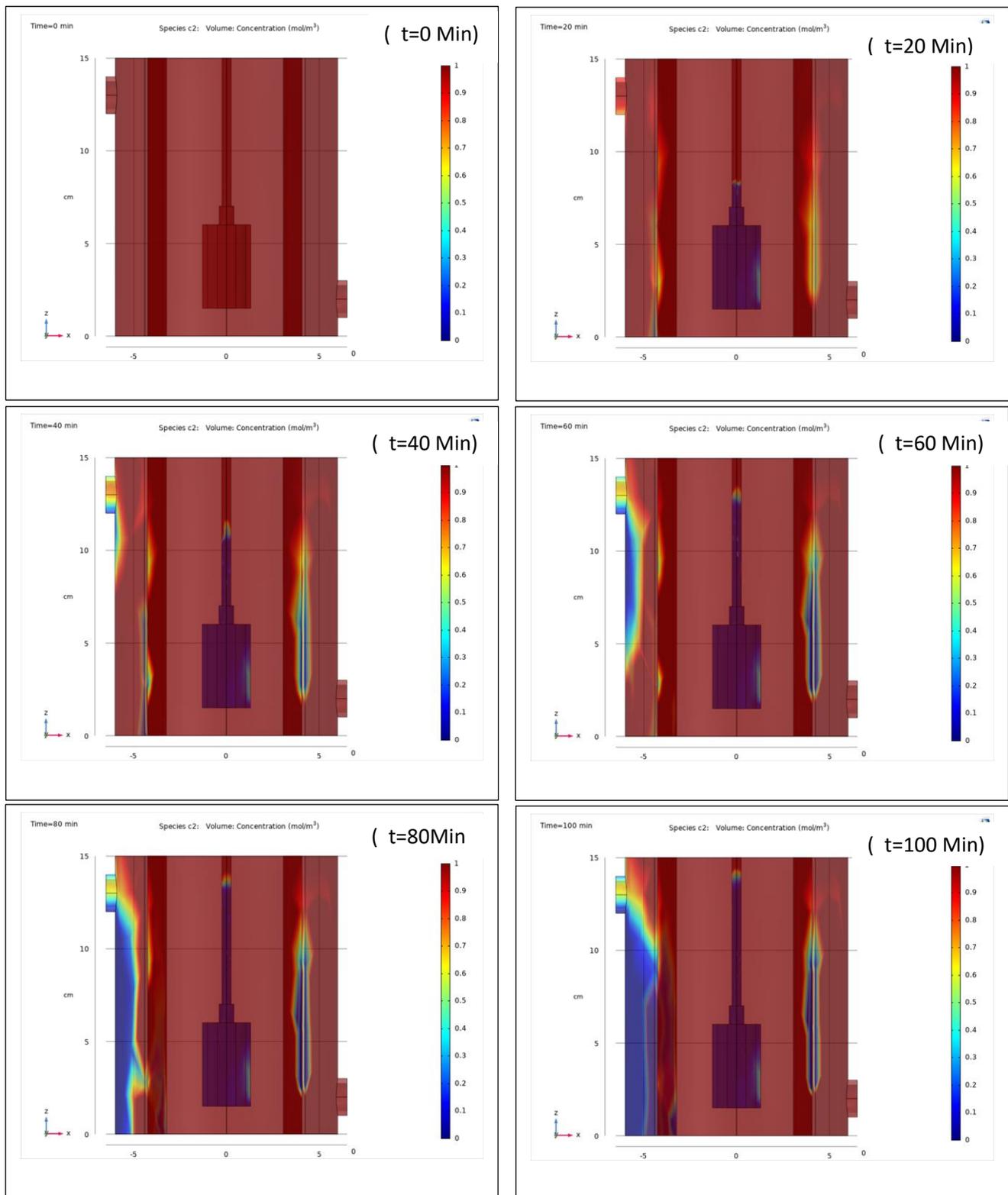


Figure (4.31) Lead distribution at $V=6V$, $HRT=30$ min , and $\text{rpm}=0$.

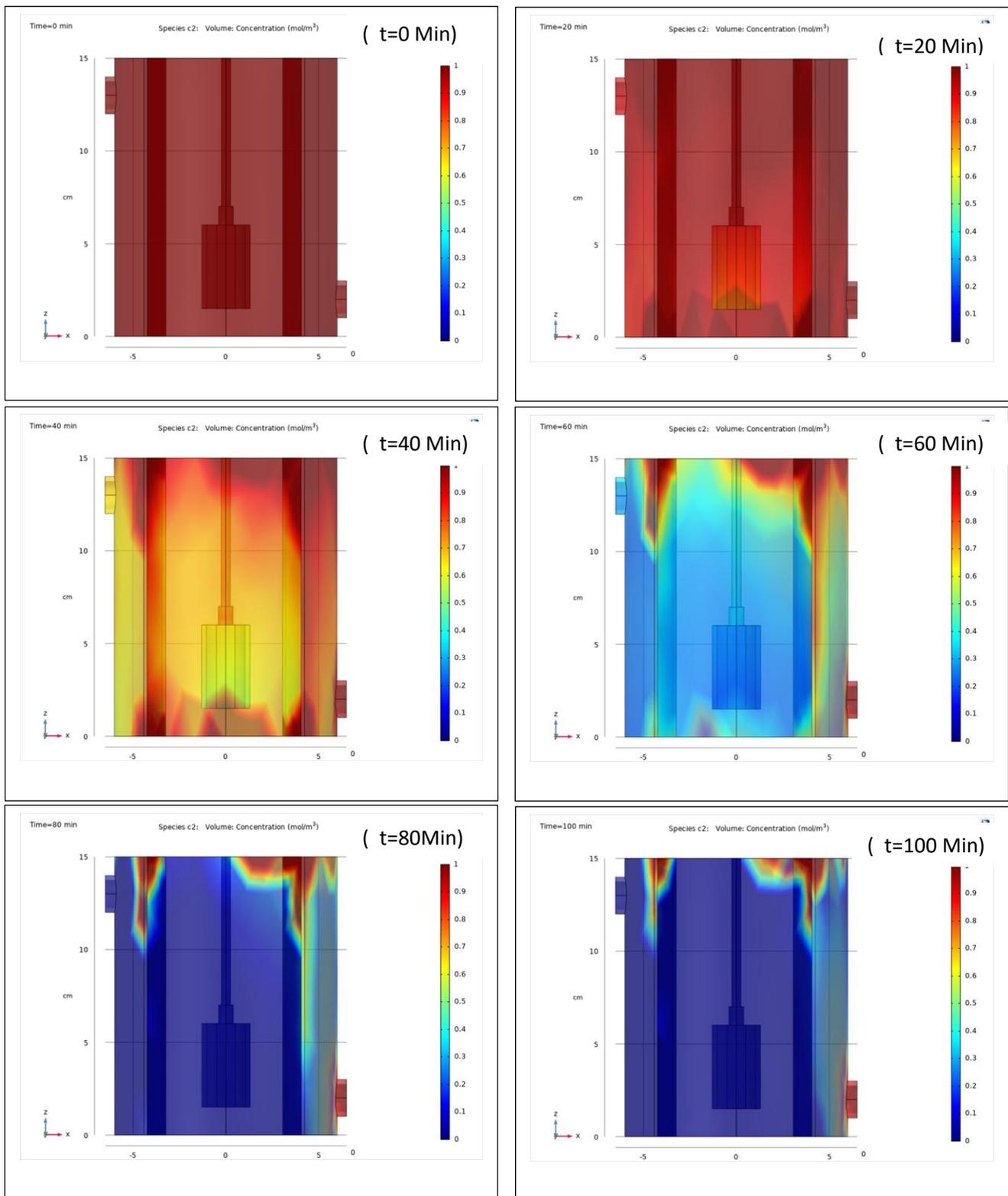


Figure (4.32) Lead distribution at HRT=30 min ,V=6V and rpm=10 .

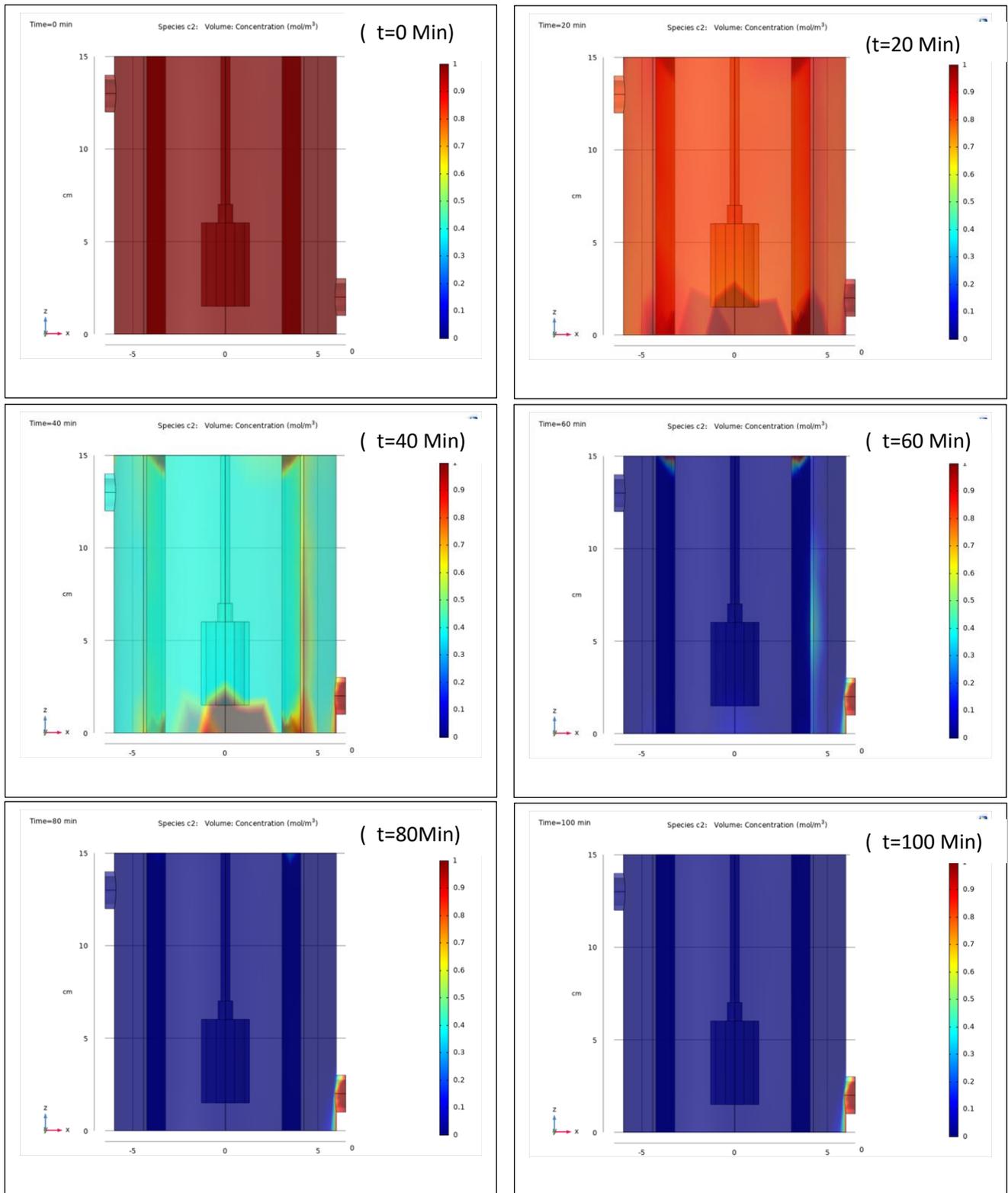


Figure (4.33) Lead distribution at $V=6V$, $HRT=30$ min and $rpm=50$.

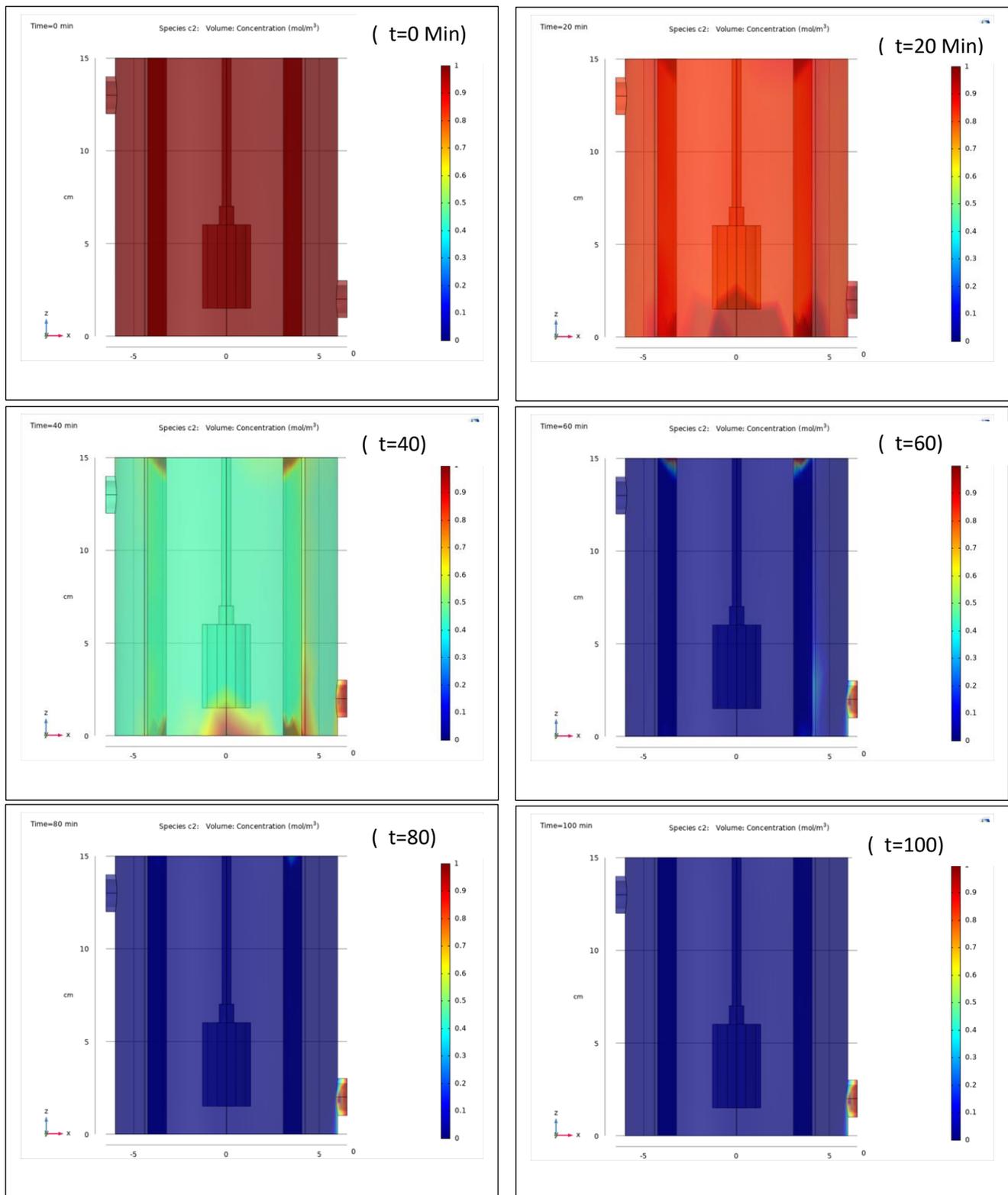


Figure (4.34) Lead distribution at $t=\text{Min}$, $V=6V$, $\text{HRT}=30$ min and $\text{rpm}=100$.

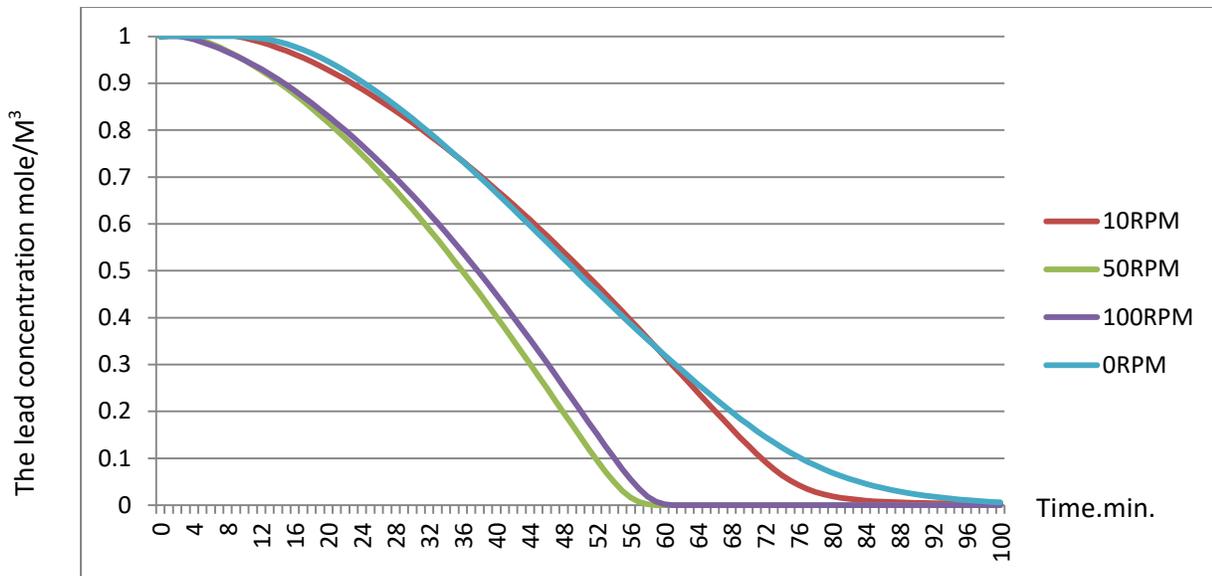


Figure (4.35) Lead distribution at V=6V and HRT=30 min.

4.9.3 Effect Of Rotating Speed On Temperature

Rotating speed helps to distribute the temperature homogeneously in the reactor, **Figures(4.36 and 37,38 and 39)** show the temperature distribution in the EC reactor with different rotating speed (0,10,50and 100 rpm) with keeping other parameters constant (applied voltage 6V and HRT 30 min.).**Figure(4.36)** shows the temperature destruction with zero rpm anode speed ,its show the temperature starts increasing with time around anode then transfer towards the outlet which the same flow rate direction. **Figures(4.37,38 and 39)** show the homogenous temperature distribution in the EC reactor due to the speed of anode ,the in temperature in the speed (10,50 and 100 rpm) is very little and can be neglected ,the advantage of rotating speed regarding to temperature is to distributed it homogeneously. **Figure (4.40)** shows the temperature at outlet of reactor with different rotating speed (0,10,50and 100 rpm) and constant (applied voltage 6V and HRT 30 min.).

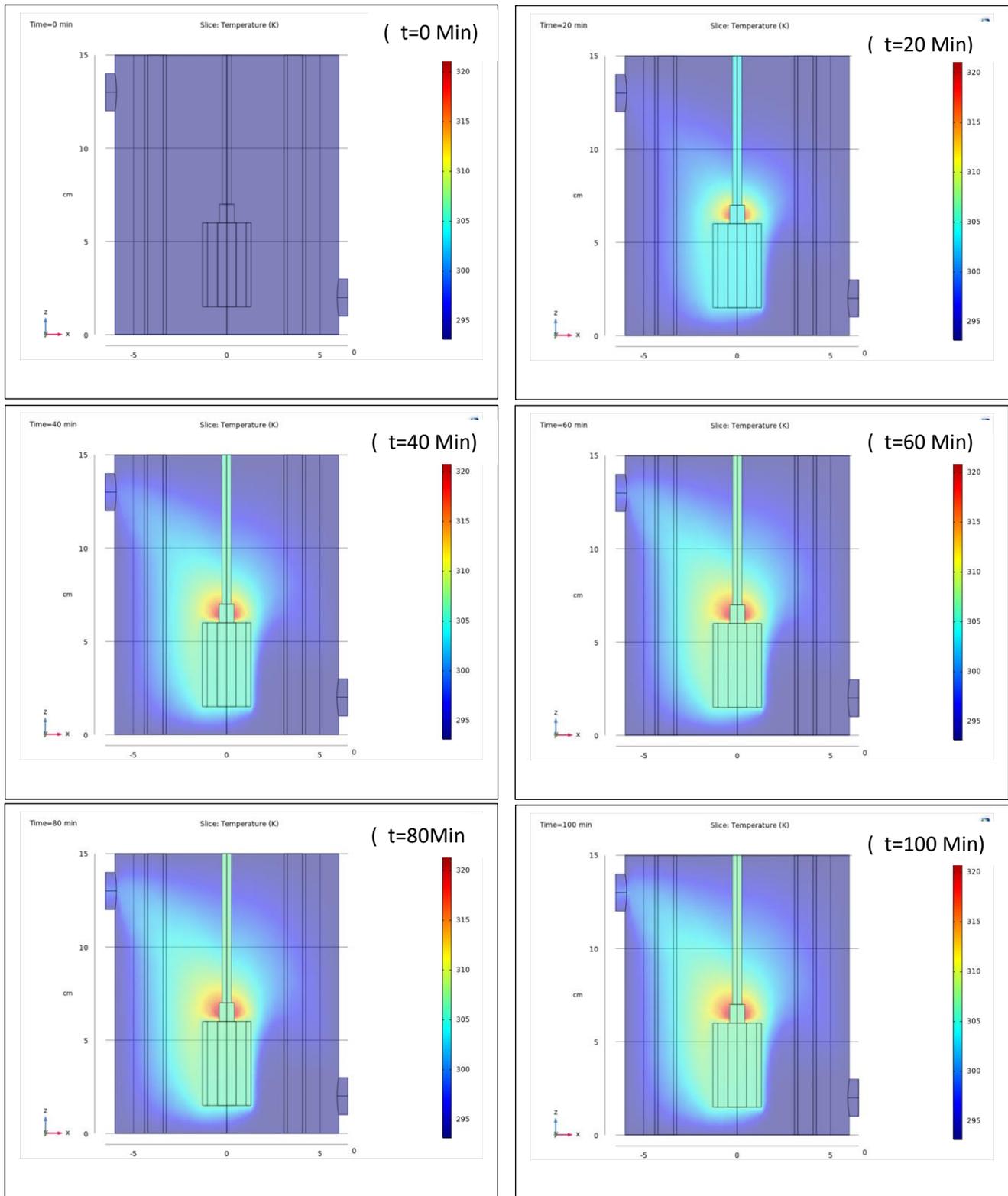


Figure (4.36) Heat distribution at V=6V, HRT=30 min ,and rpm=0.

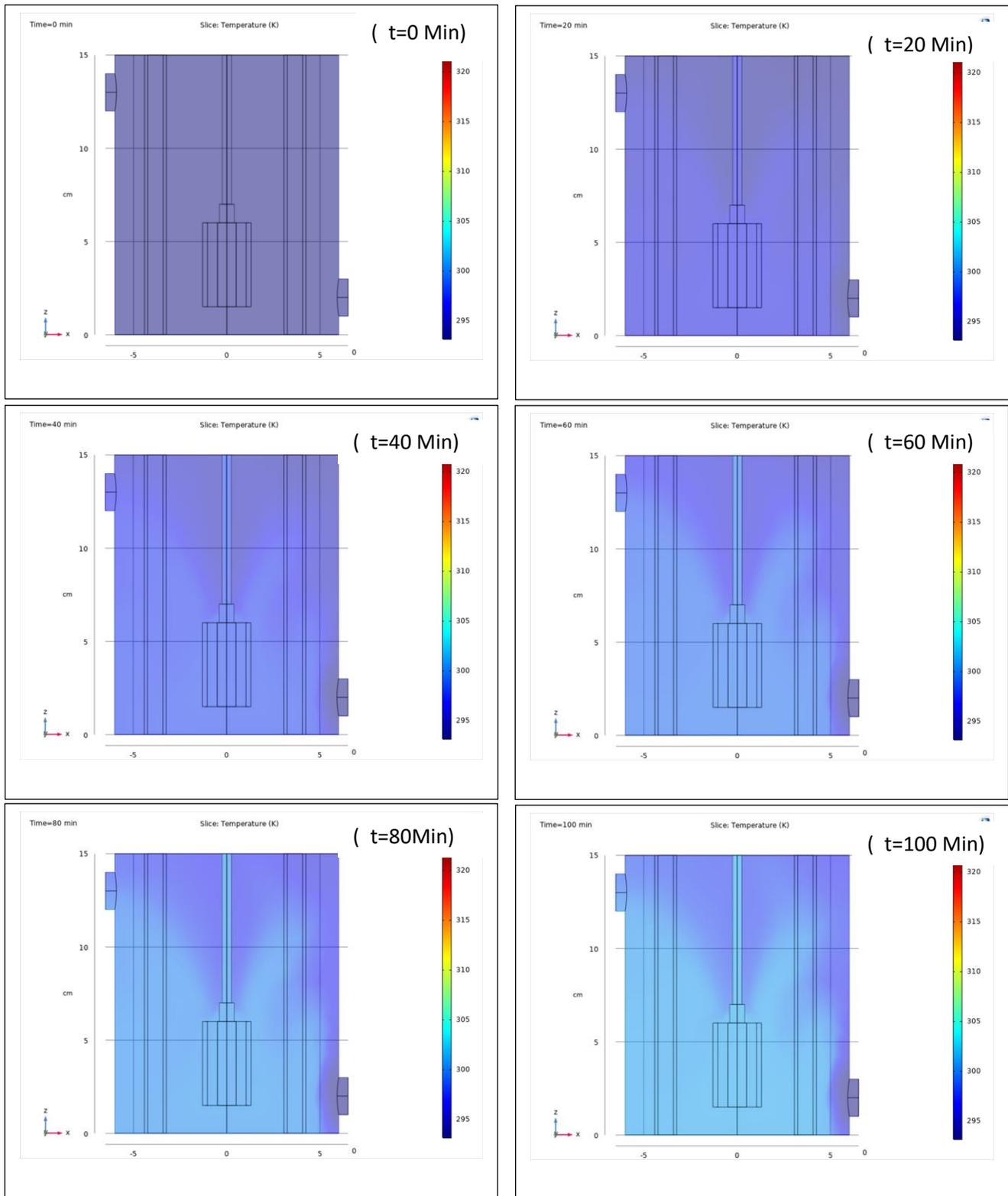


Figure (4.37) Distribution of heat at HRT=30 min ,V=6V and rpm=10.

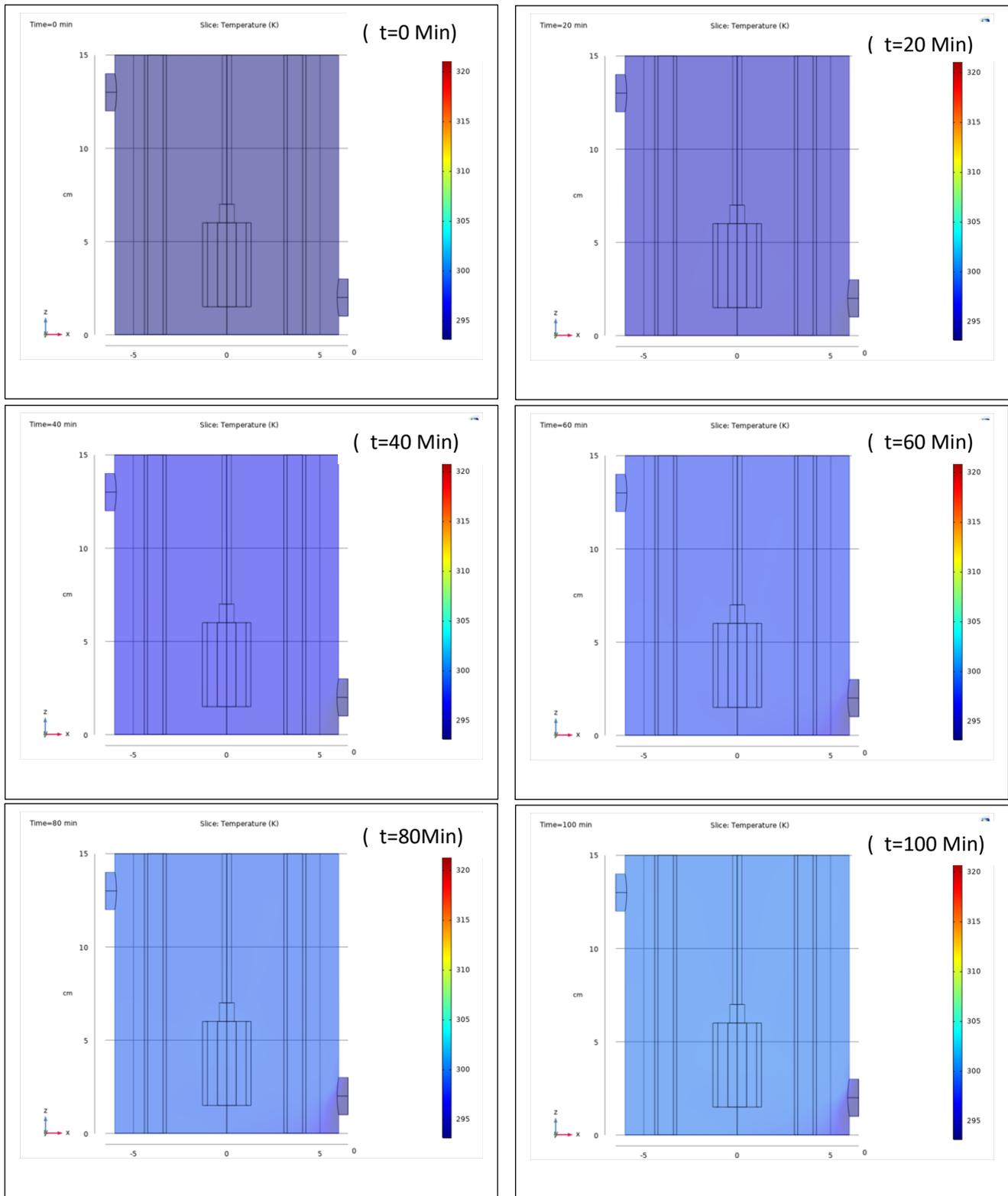


Figure (4.38) Distribution of heat (HRT=30 min ,V=6V and rpm=50 .

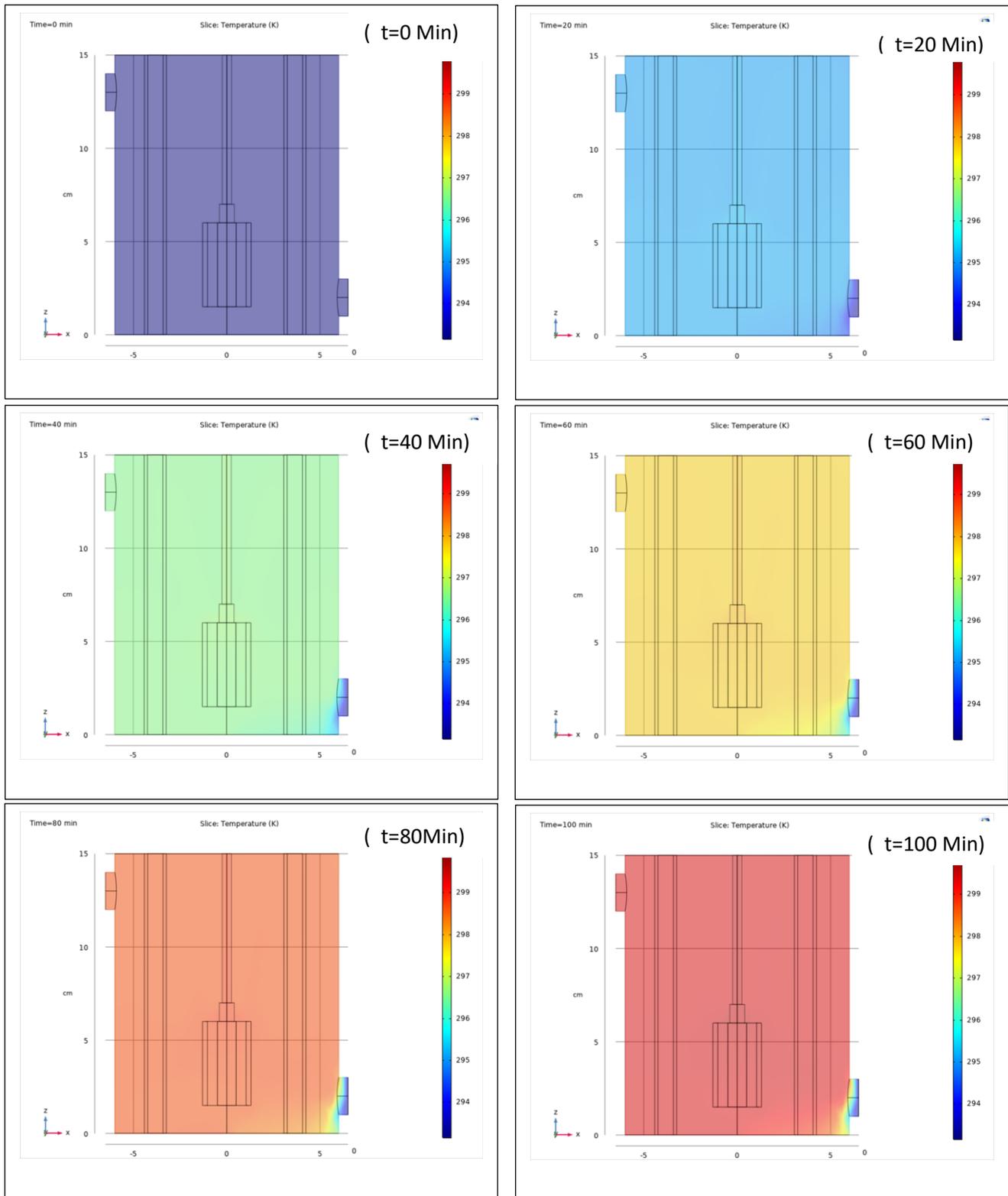


Figure (4.39) Distribution of heat at HRT=30 min ,V=6V and rpm=100 .

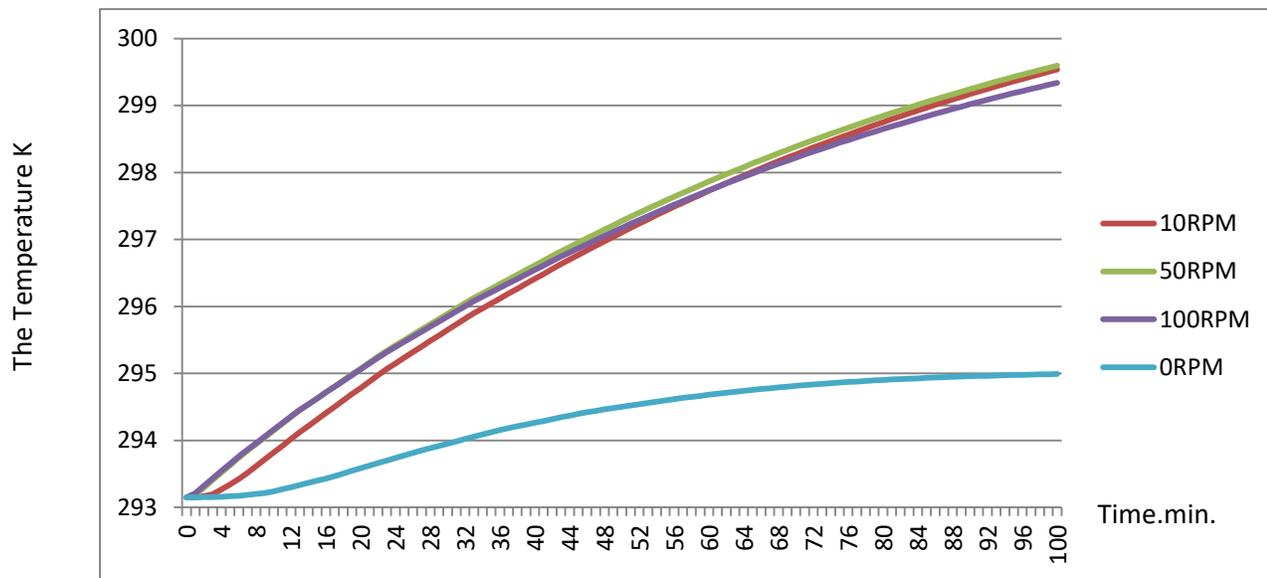


Figure (4.40) Distribution Temperature in the EC reactor at HRT=30 min ,V=6V .

4.10. Effect Of HRT

HRT is the velocity of the inlet flow rates of the polluted water .Its defined as following :

$$\text{HRT} = V_R / Q$$

Where V_R = reactor volume (800 Cm^3), Q_i volumetric flow rate (M^3/S).

The below result depending on the following parameters (6V,50rpm) and (10,20,30 and 40 HRT).

4.10.1 Effect of HRT on the coagulants production

HRT influence on the EC reactor is less than other parameters because the reaction too fast ,that makes the effect of HRT not effecting in this case.

Figures(4.41,42,43 and 44) show the coagulants productions at different HRT(10,20,30 and 50 min.) and constant the other parameters(6 V applied voltage and 50 rpm),all figures almost same without changing ,that show the effect of HRT is not significant because the reaction is too fast. **Figure (4.45)** shows the coagulants distribution at reactor outlet with different HRT.

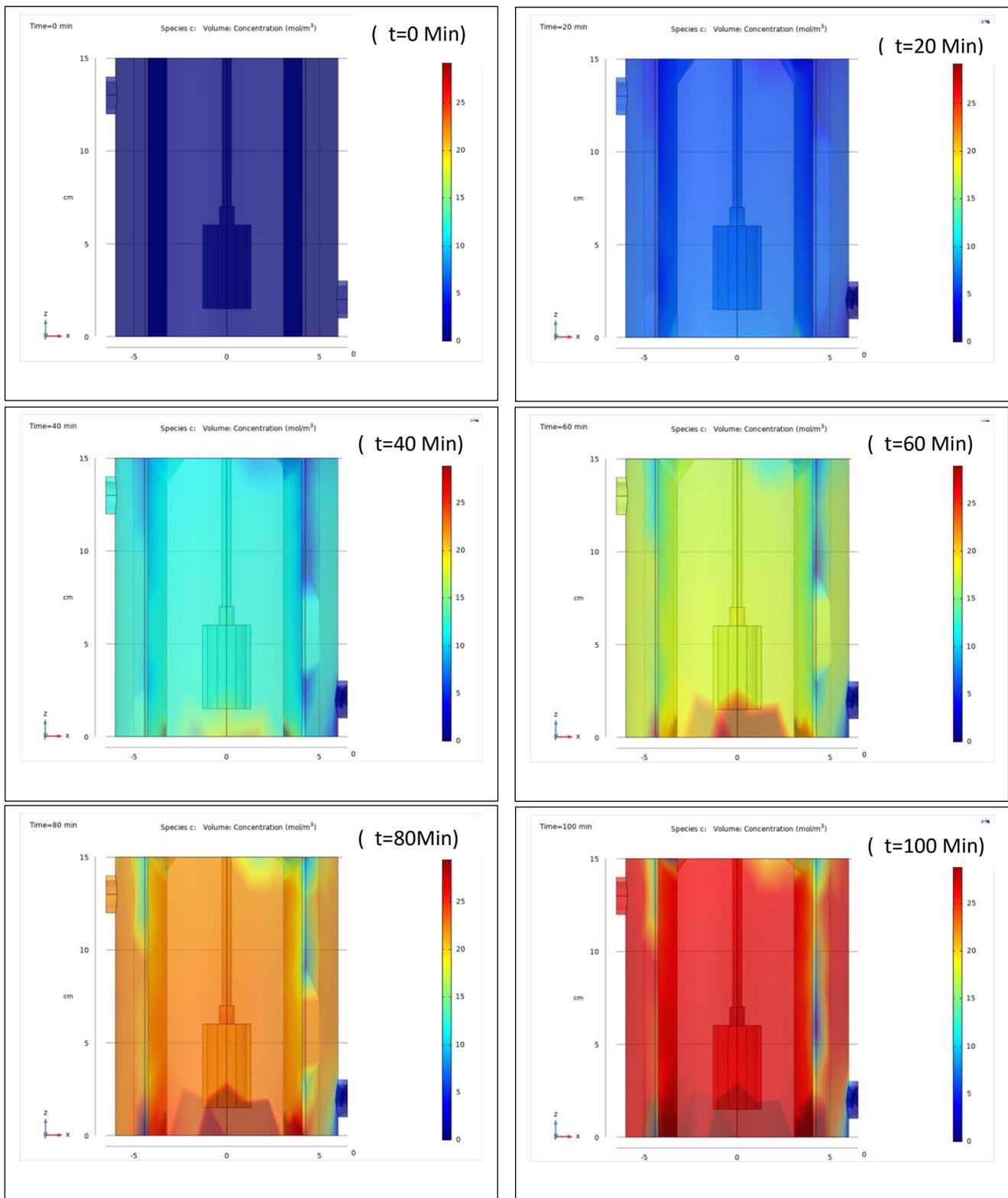


Figure (4.41) Distribution of Coagulants at HRT=10 min , V=6V and rpm=50 .

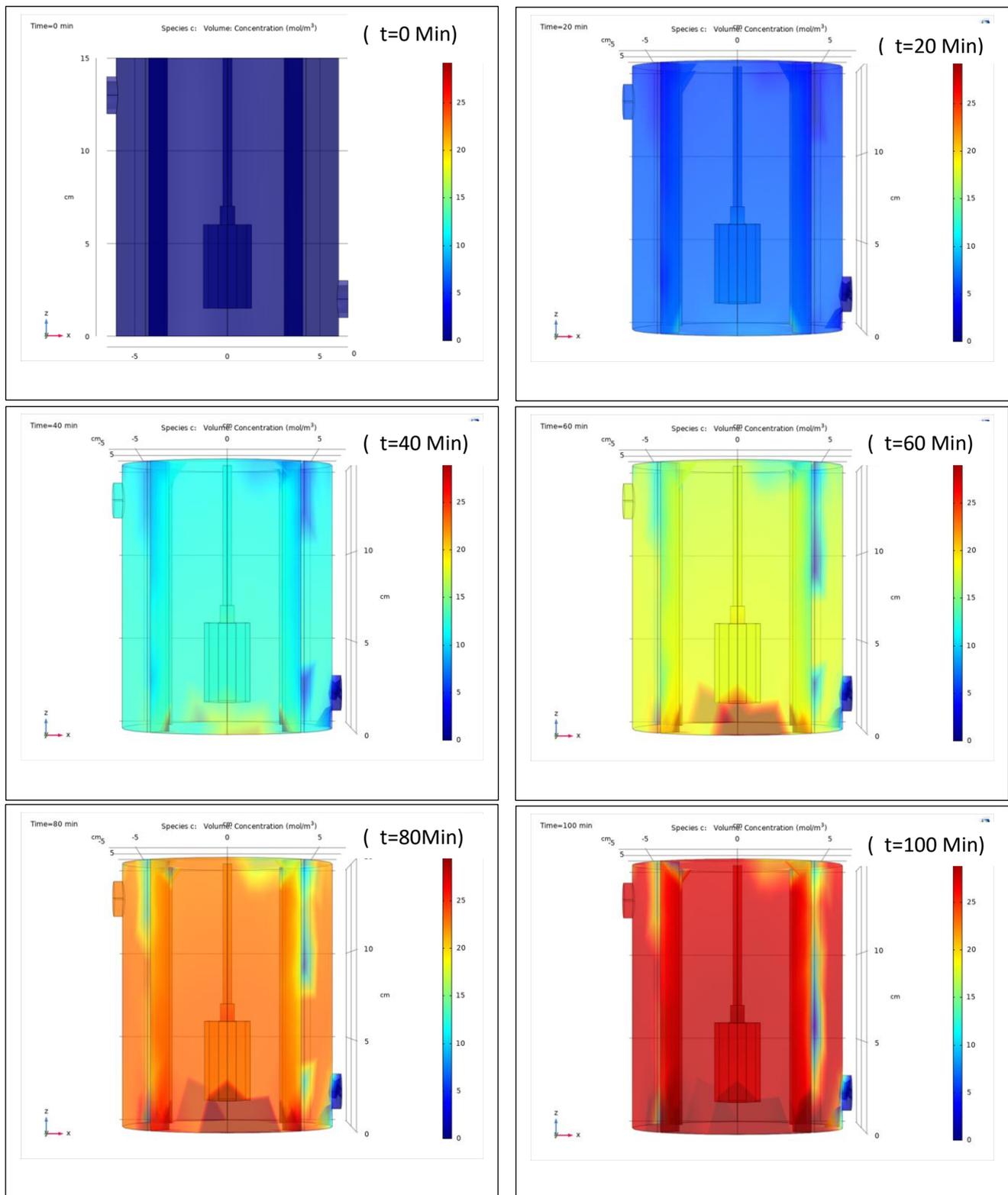


Figure (4.42) Distribution of Coagulants in the EC reactor at HRT=20 min ,V=6V and rpm=50 .

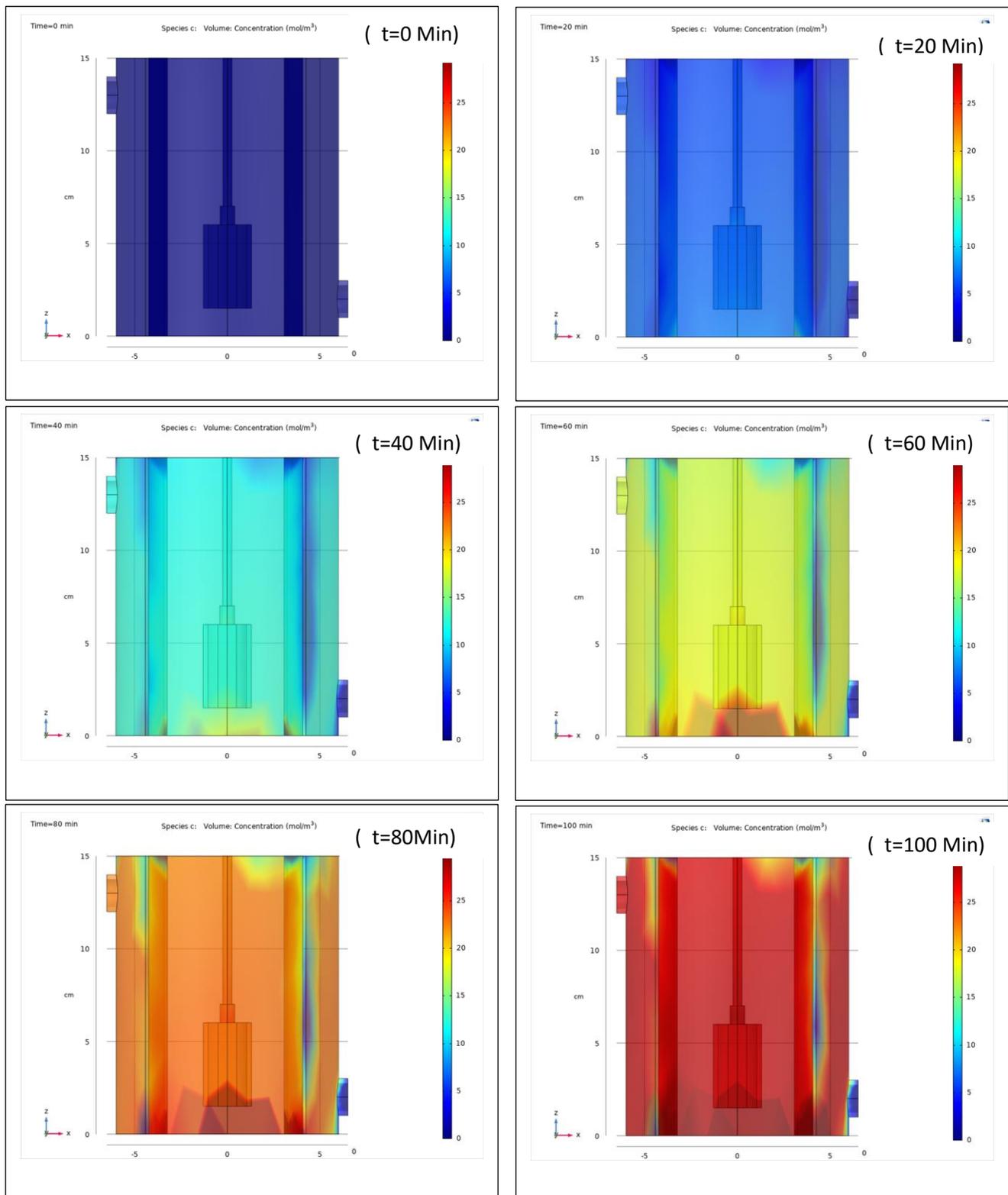


Figure (4.43) Distribution of coagulants in the EC reactor at HRT=30 min , V=6V and rpm=50 .

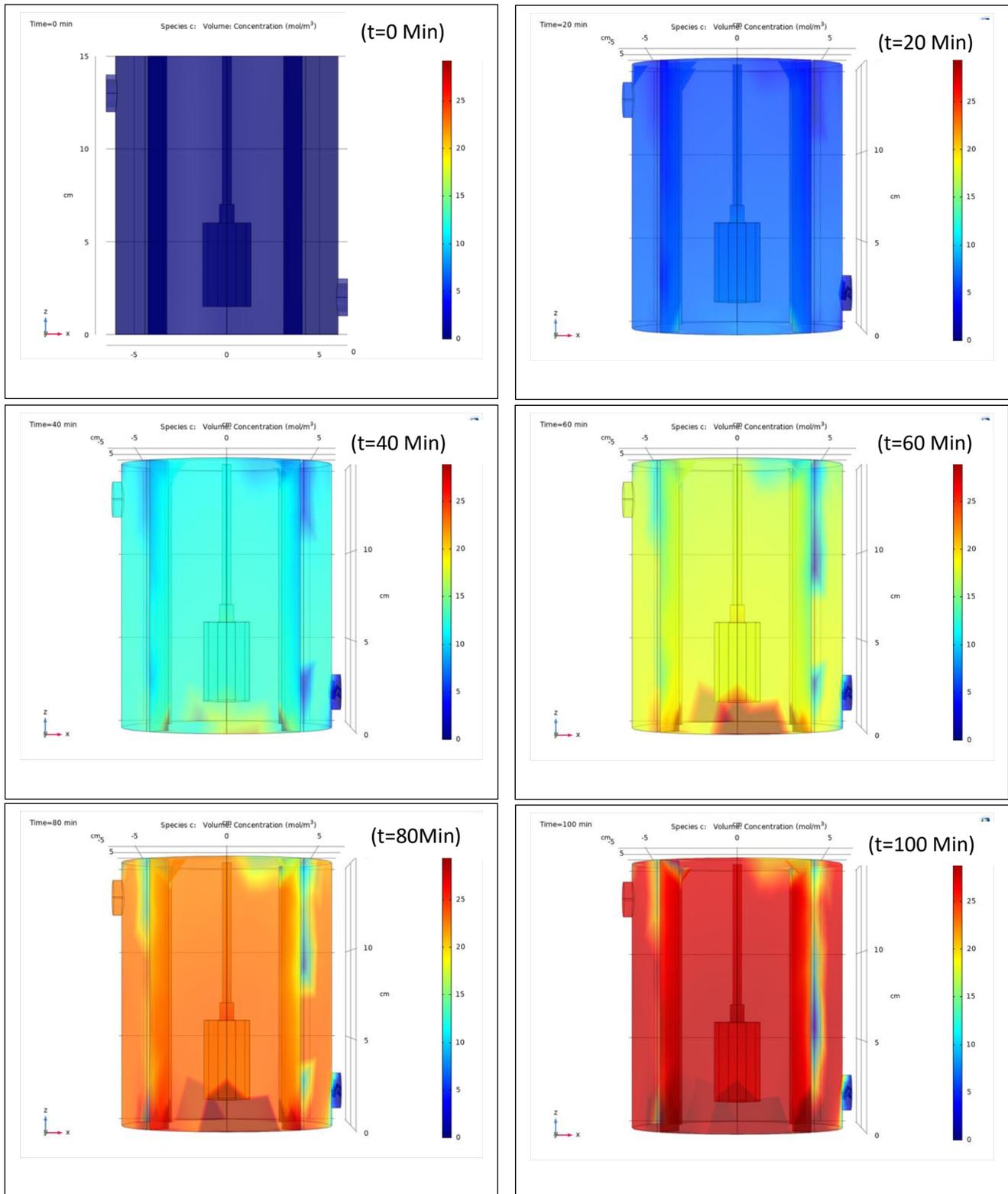


Figure (4.44) Distribution of Coagulants in the EC reactor at HRT=40 min , V=6V and rpm=50 .

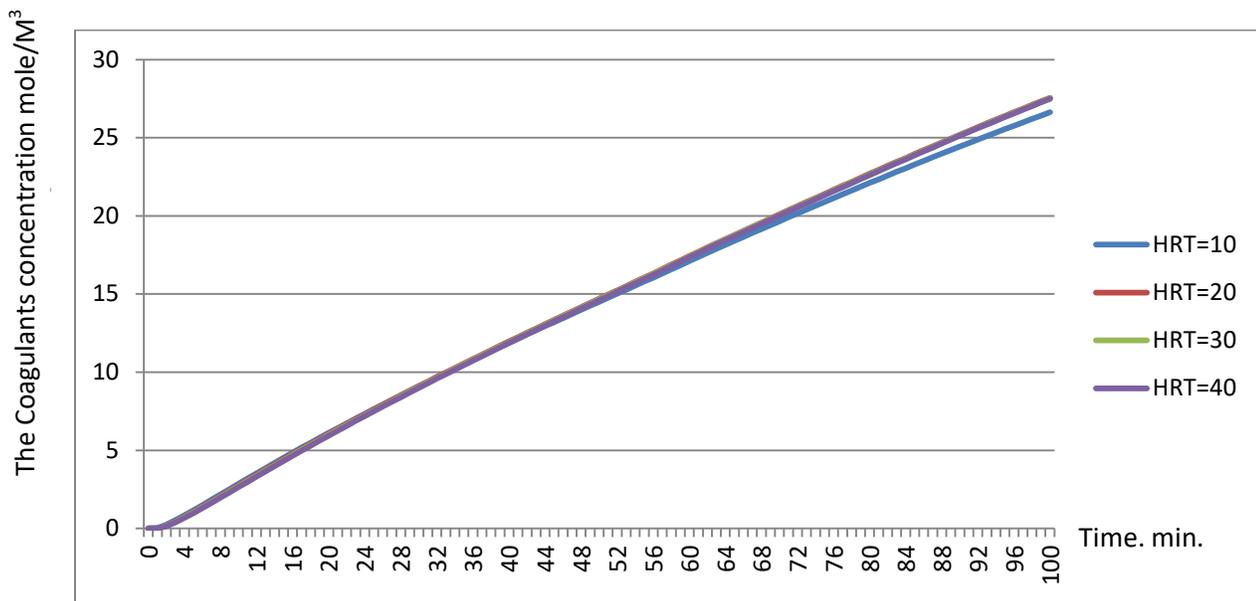


Figure (4.45) Distribution of Coagulants in the EC reactor at 6V and 50 rpm.

4.10.2 Effect of HRT on lead distribution concentration

The **Figures(4.46,47,48 and 49)** at different HRT value(10,20,30 and 50 min.)with constant other parameters(6 V applied voltage and 50 rpm) show the lead removal with changing HRT, the effect of HRT is very small ,because the reaction is very fast , changing in HRT doesn't effect on the lead concentration ,as result of not changing in coagulants concentration , **Figure (4.50)** shows the lead distribution at outlet of reactor with different HRT (10,20,30 and 50 min.)with constant other parameters(6 V applied voltage and 50 rpm).

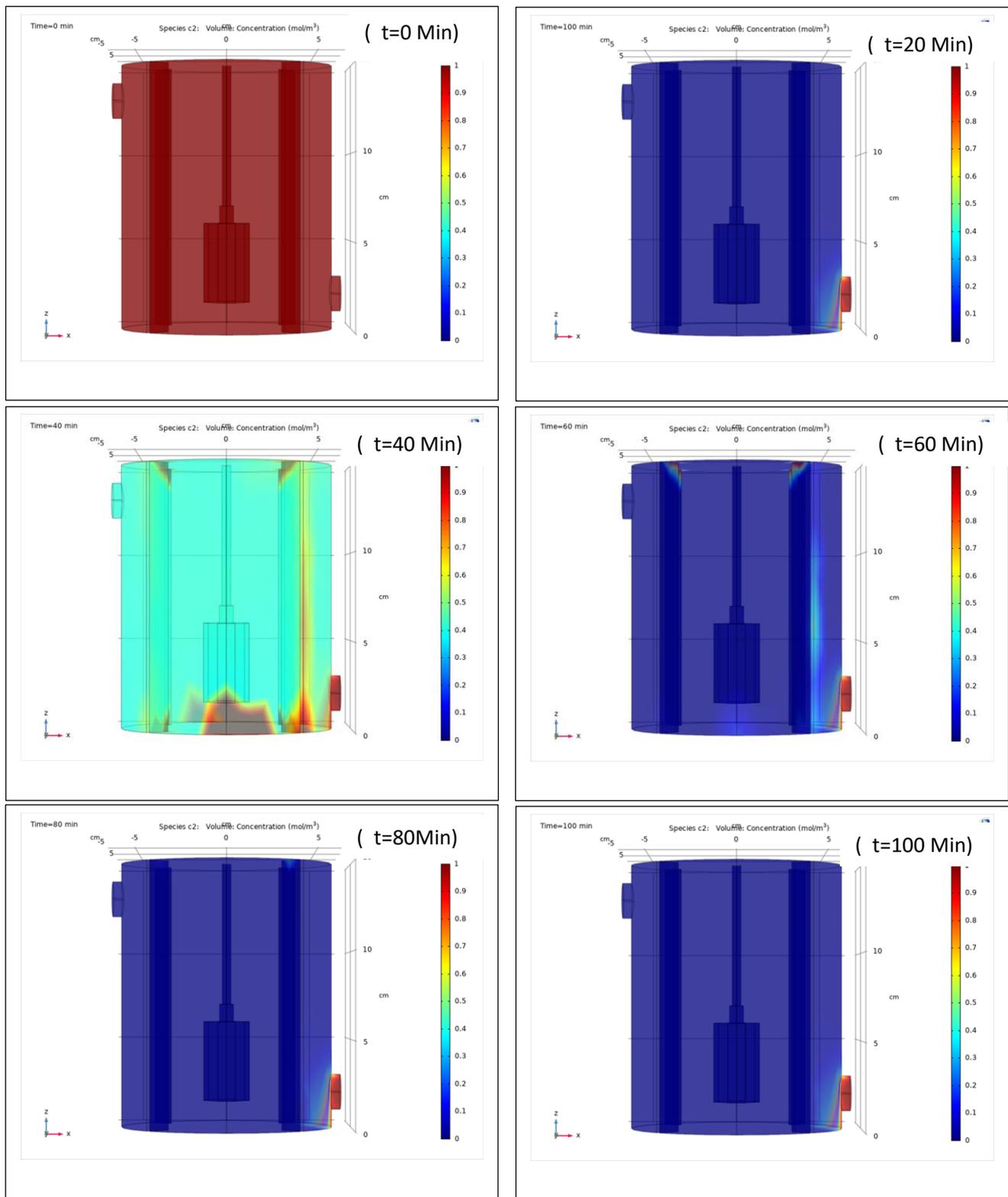


Figure (4.46) Lead distribution at $V=6V$, $HRT=10$ min and $rpm=50$.

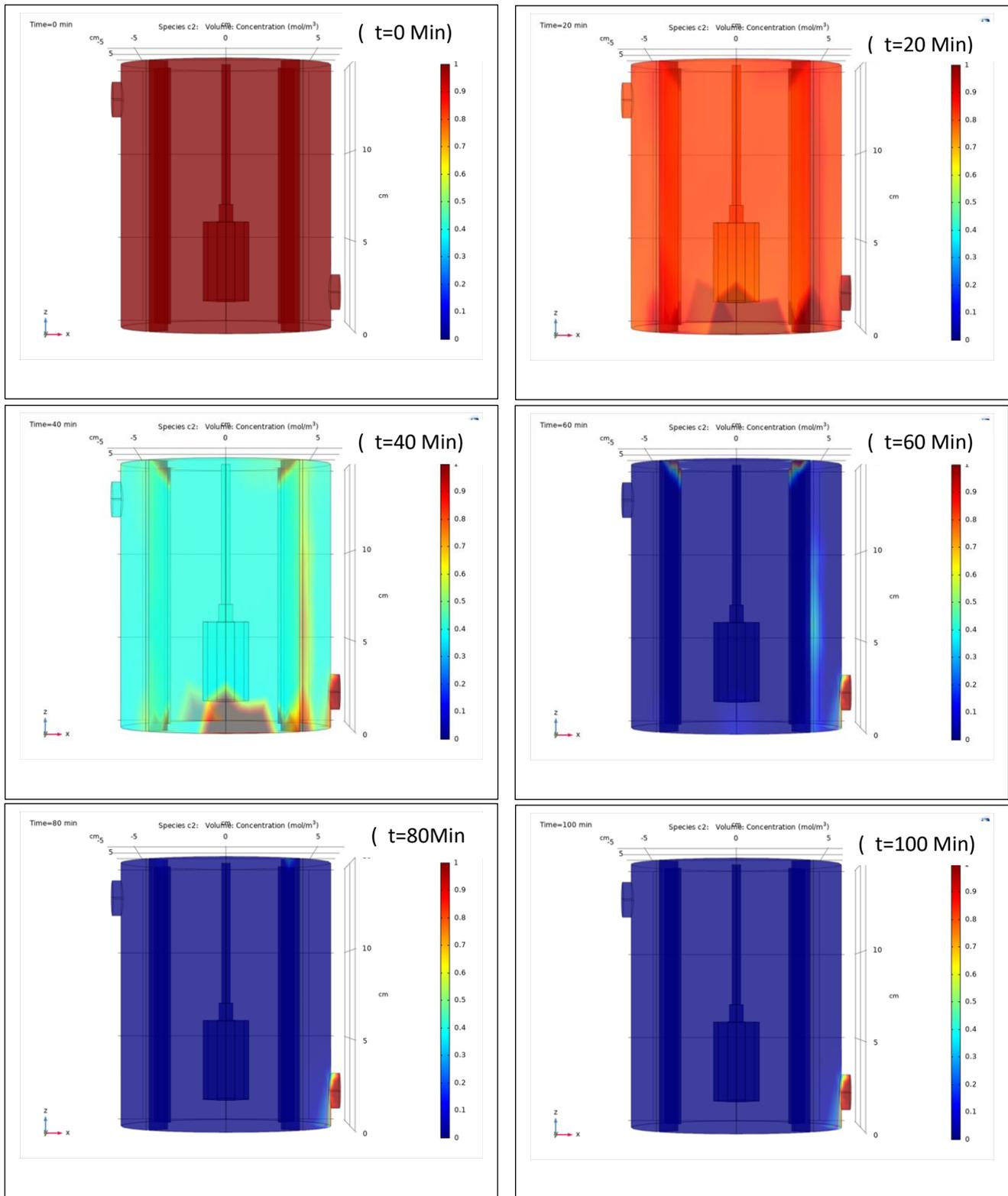


Figure (4.47) Lead distribution at HRT=20 min ,V=6V and rpm=50 .

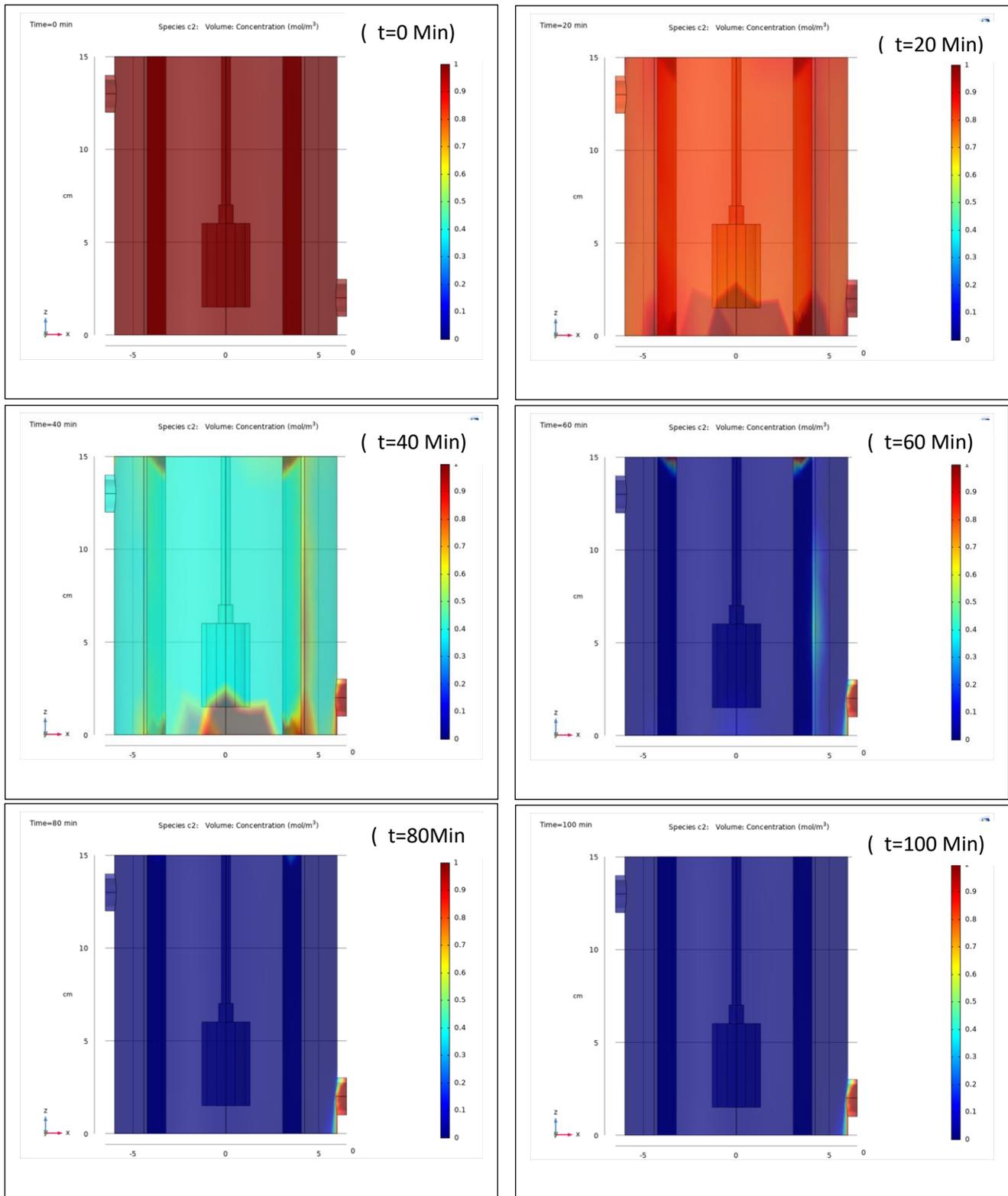


Figure (4.48) Lead distribution at V=6V, HRT=30 min and rpm=50 .

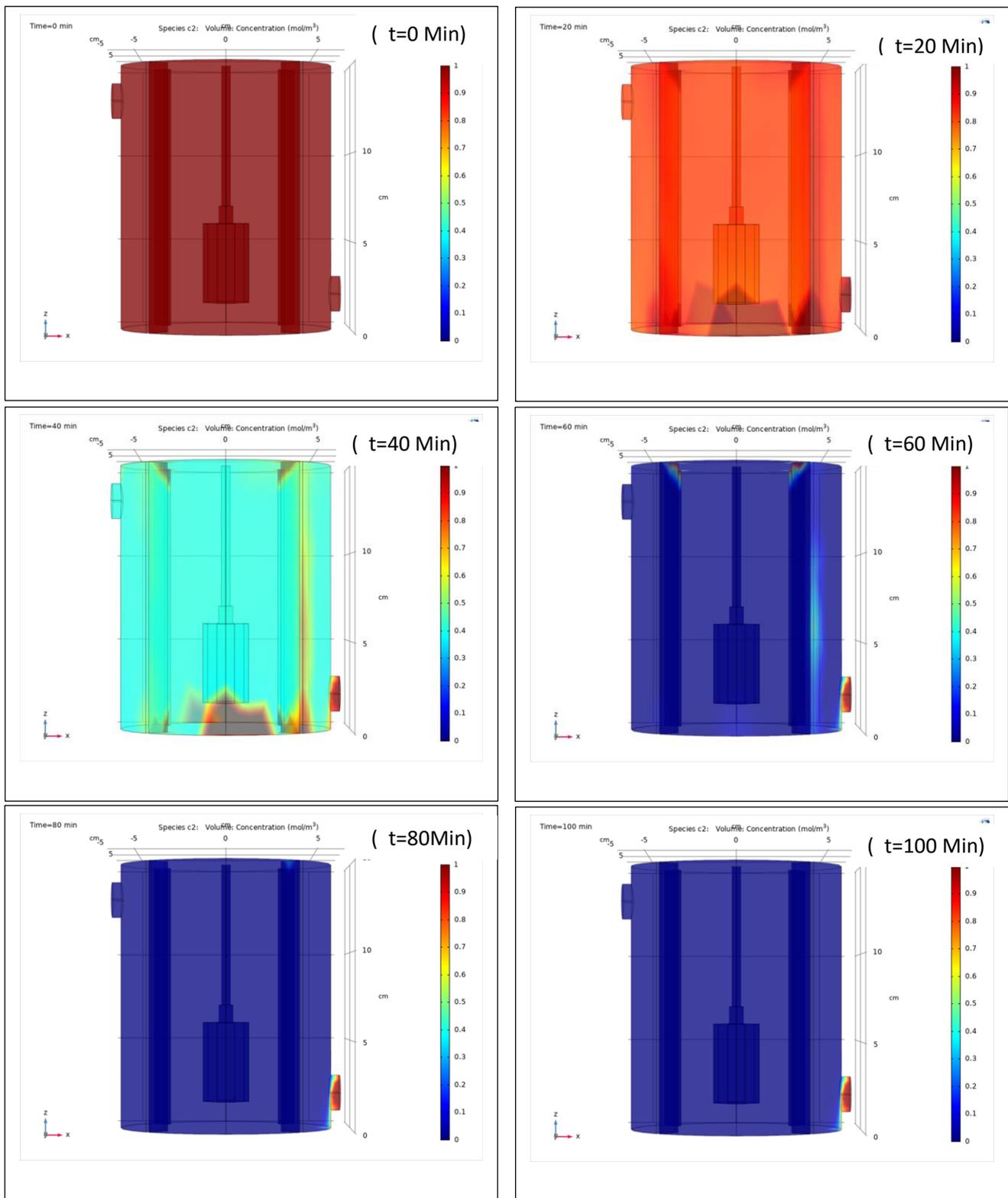


Figure (4.49) Lead distribution at $V=6V$, $HRT=40$ min and $rpm=50$.

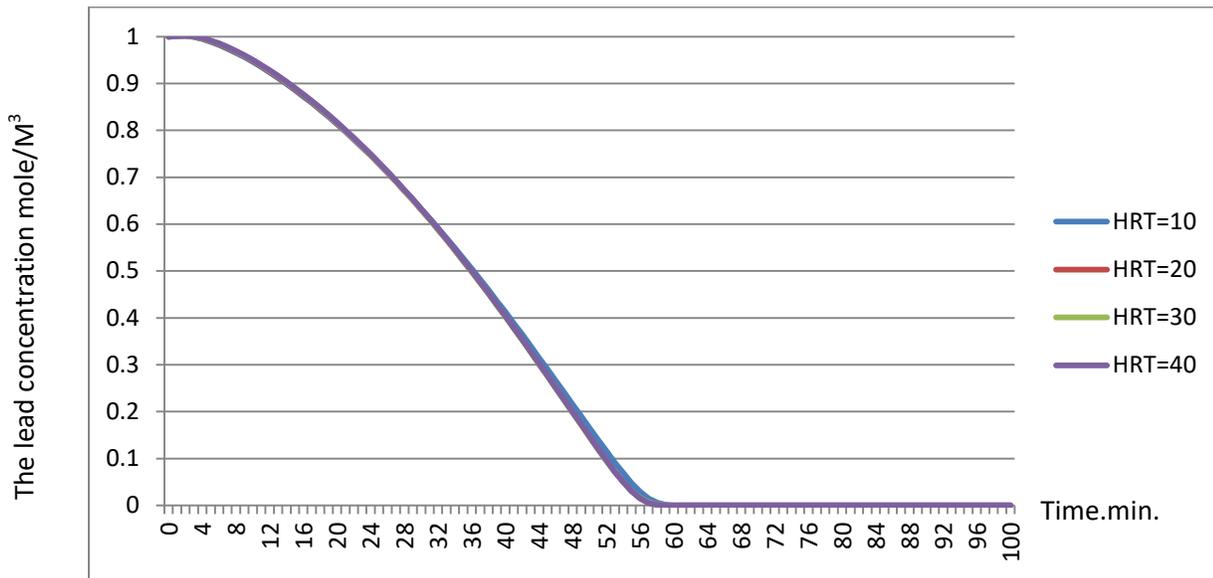


Figure (4.50) Lead distribution at 6V and 50 rpm.

4.10.3 Effect of HRT on temperature distribution

Figures (4.51,52,53 and 54) below show the effect of HRT at different HRT value (10,20,30and 50 mins) with keeping other parameters constant (6V applied voltage and 50 rpm)on the reactor temperature. The temperature increases as HRT increasing, when time of residual wastewater be longer the temperature become hotter as the voltage keep continues to the cell and the metal resistance generating the temperature ,**Figure (4.55)**shows the temperature distribution at different HRT value (10,20,30and 50 min.) with keeping other parameters constant (6V applied voltage and 50 rpm)at reactor. The main source of temperature is the resistant of anode material which is the source of external power .

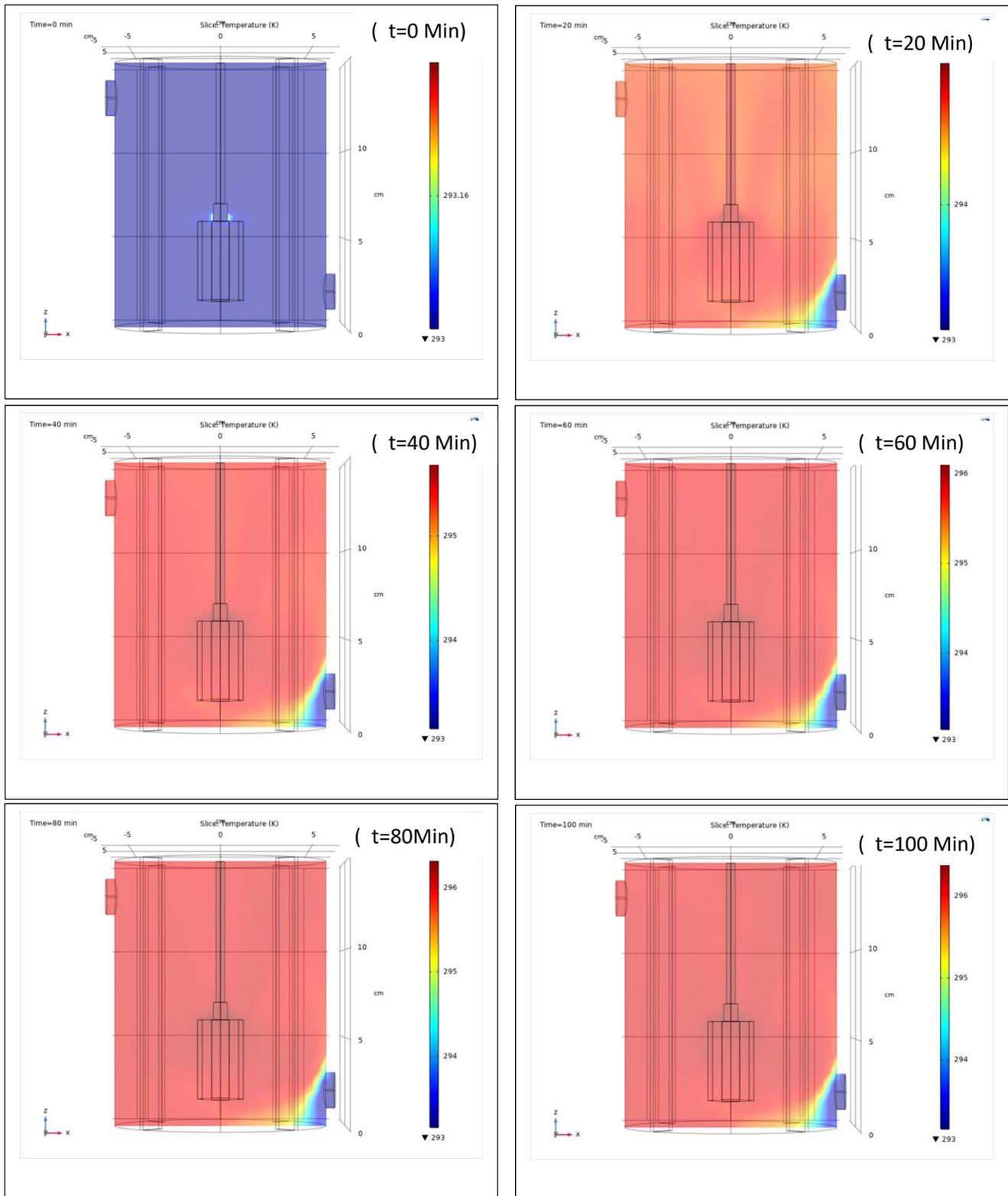


Figure (4.51) Distribution of temperature in the EC reactor at HRT=10 min ,V=6V and rpm=50 .

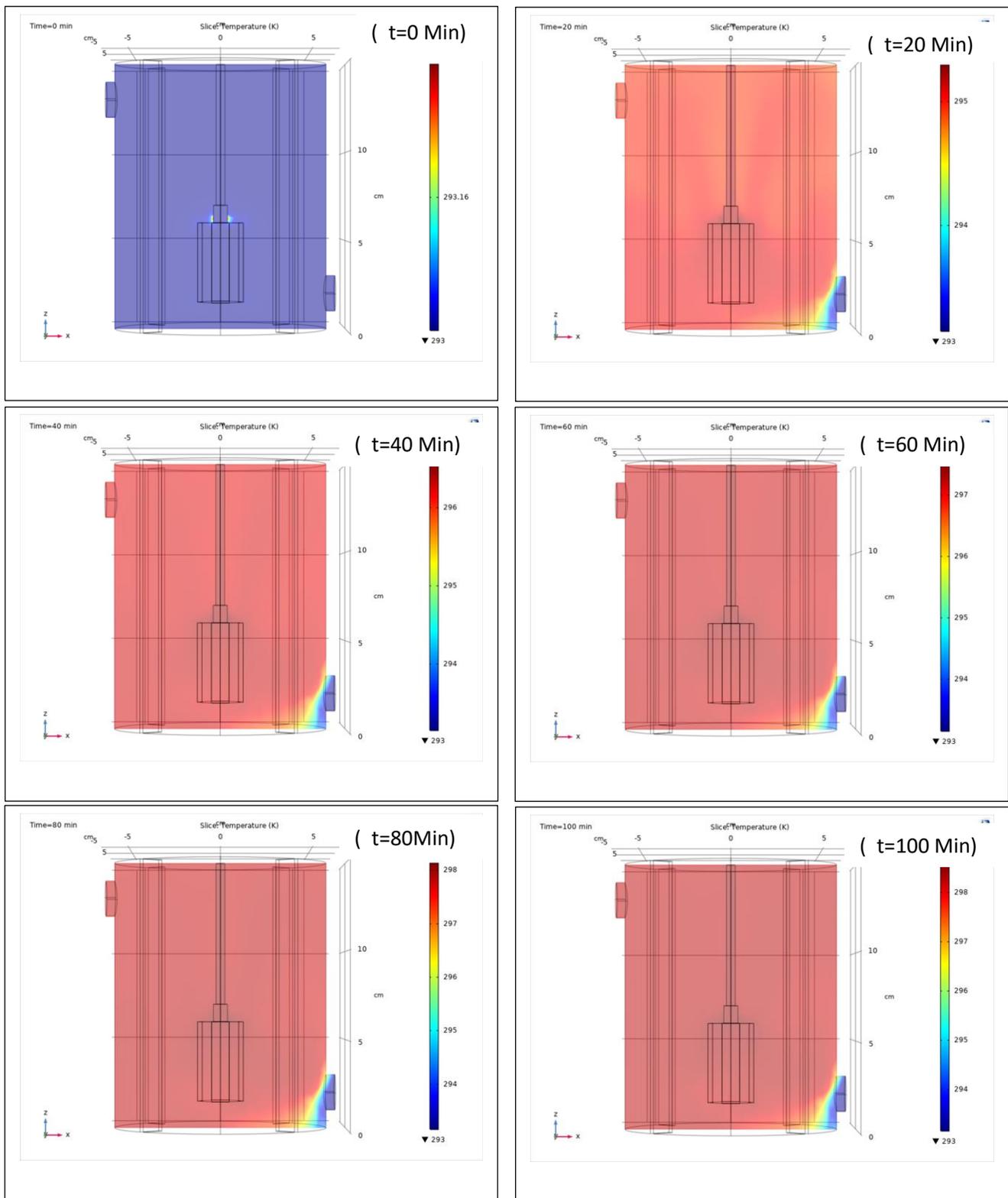


Figure (4.52) Distribution of temperature in the EC reactor at HRT=20 min ,V=3V and rpm=50 .

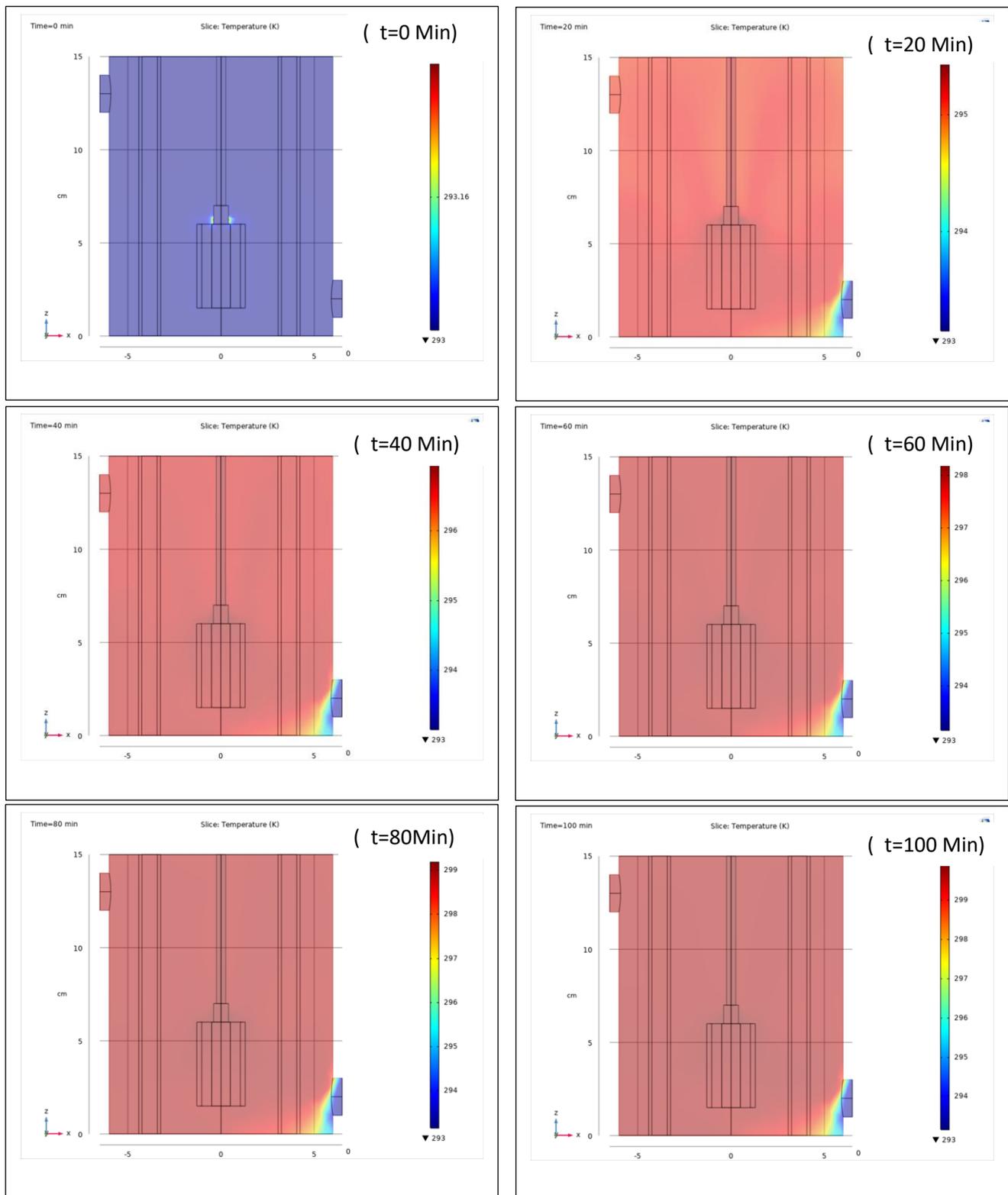


Figure (4.53) Distribution of temperature in the EC reactor at HRT=30 min ,V=6V and rpm=50 .

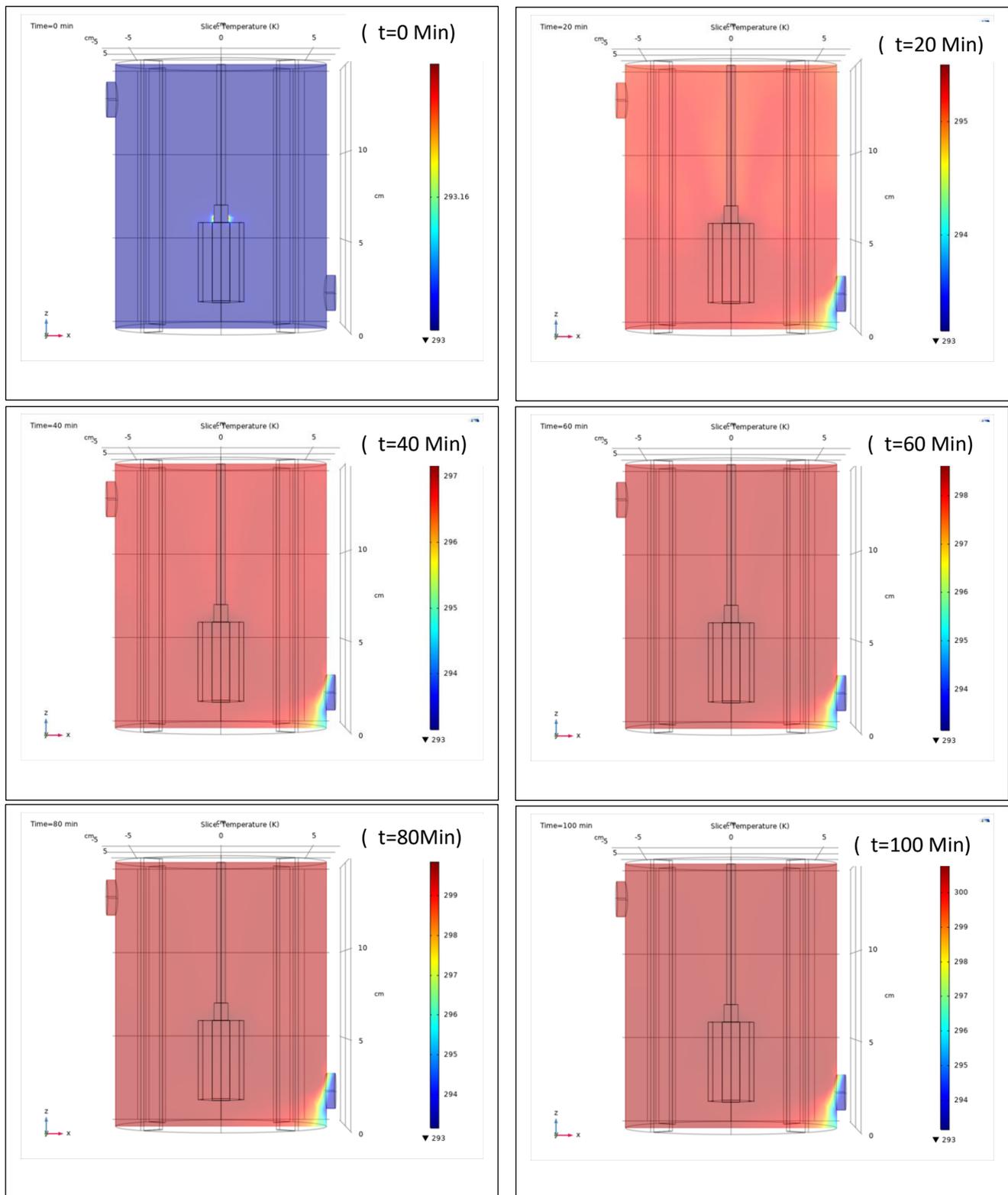


Figure (4.54) Distribution of temperature in the EC reactor at HRT=40 min , $V=6V$ and rpm=50 .

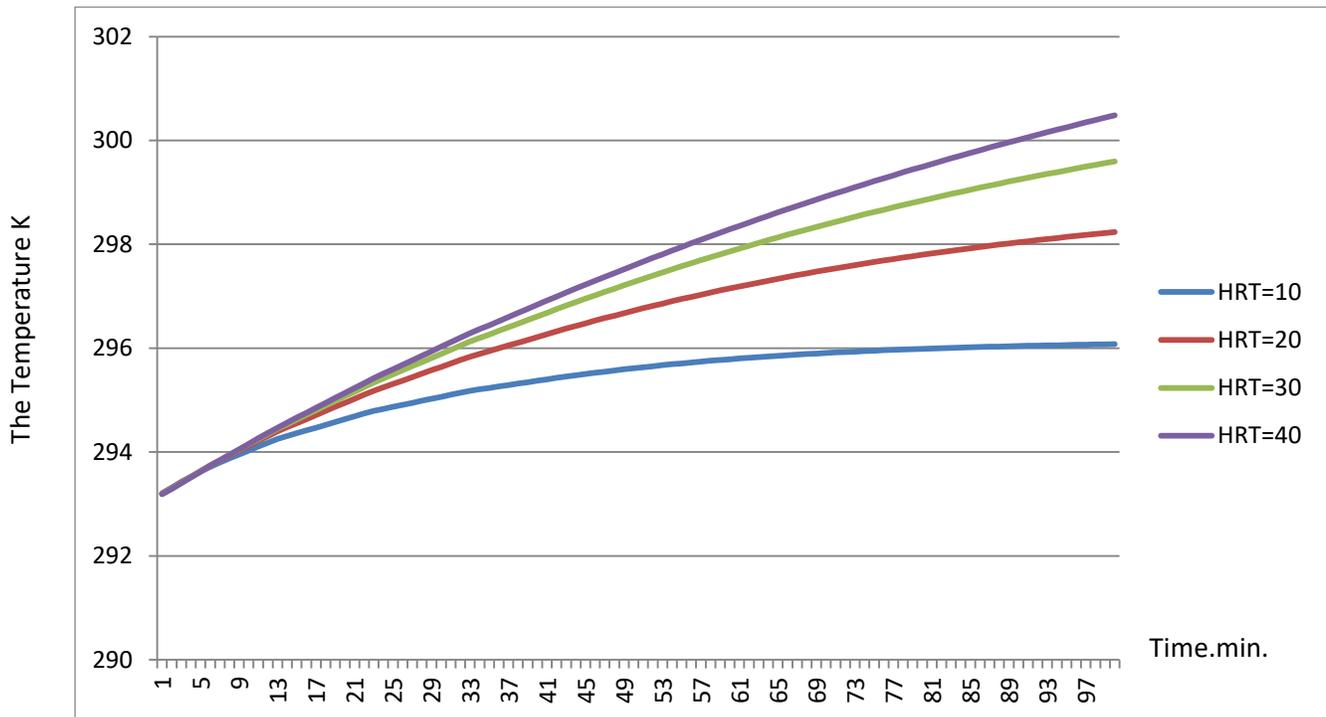


Figure (4.55) Distribution of Temperature in the EC reactor at 6V and 50rpm .

4.11 Isothermal Process

The concentration distribution of coagulants and lead don't effected by the temperature as in the **Figures(4.56,57,58,59,60,61 and 62)** .By comparison the result in isothermal case with non-isothermal case result ,there is no changing in concentration distribution in coagulants and lead in both cases, that belong to the fast reactions of coagulants productions and lead with these coagulants which they are Al^{+3} ions in this case .**Figures (4.56,57 and 4.61,62)** have same coagulants productions and distribution in spite of **Figure (4.56and57)** in isothermal case and **Figure (4.61and62)** in no isothermal case. **Figures (4.58,59 and 4.63,64)** have same lead removal rate in spite of **Figure (4.58and59)** in isothermal case and **Figure (4.63,64)** in no isothermal case. **Figure (4.60)** shows the temperature in isothermal case in which the temperature is almost stable while **Figure (4.65)** shows the temperature in non-isothermal case in which the temperature is increased .

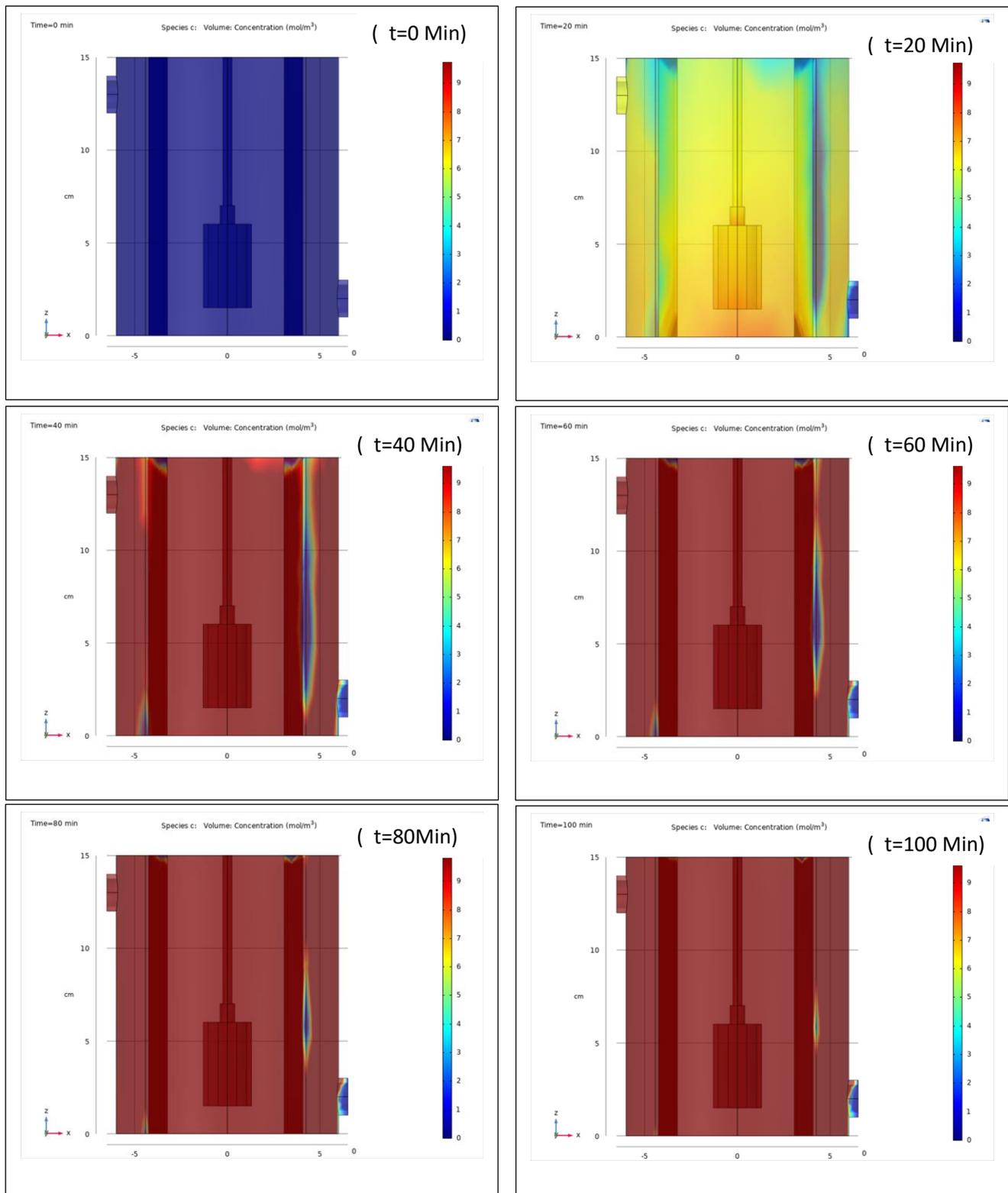


Figure (4.56) Distribution of coagulants in the EC reactor at HRT=30 min , V=6V and rpm=50 .

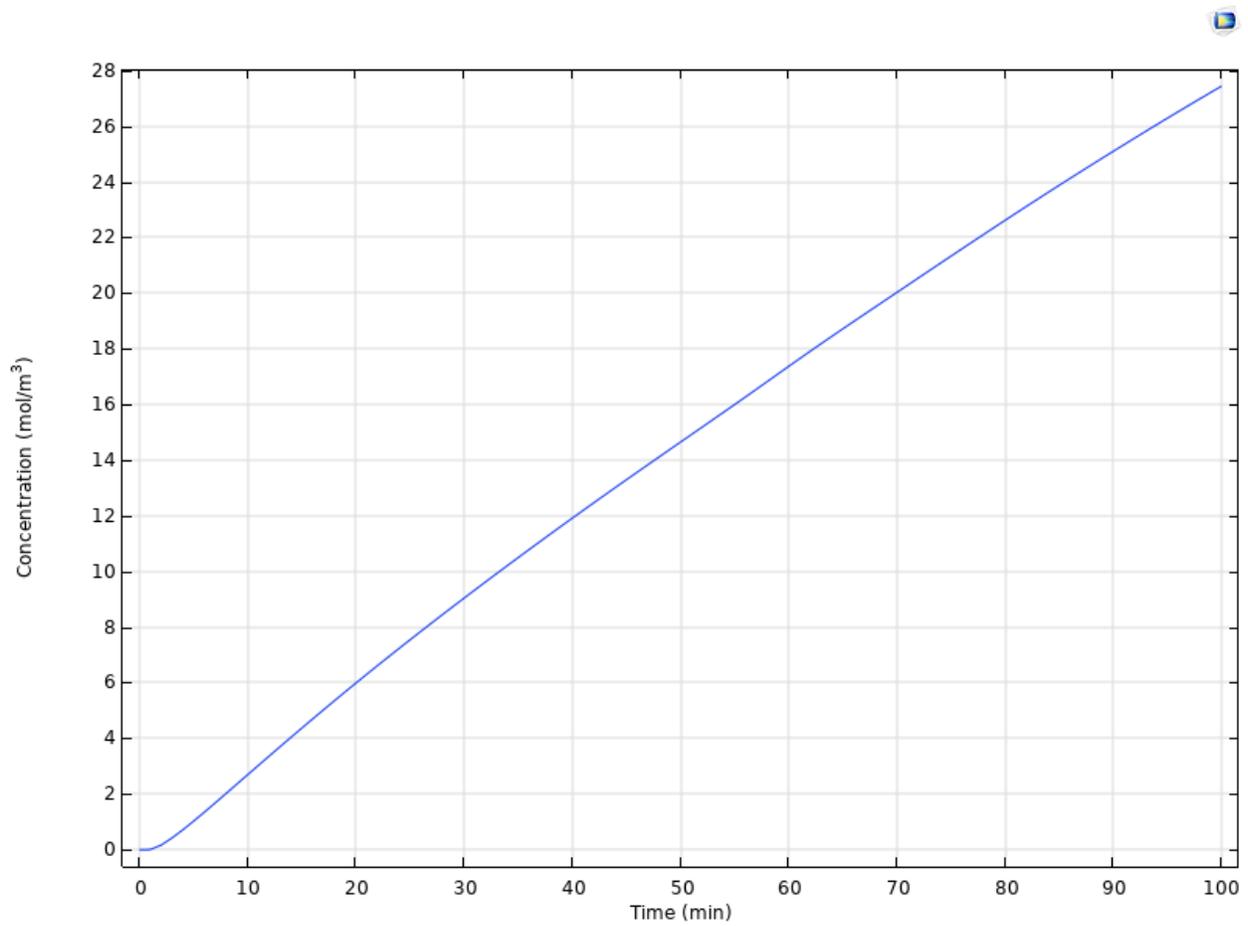


Figure (4.57) Coagulants concentration in the EC reactor at HRT=30 min ,V=6V and rpm=50.

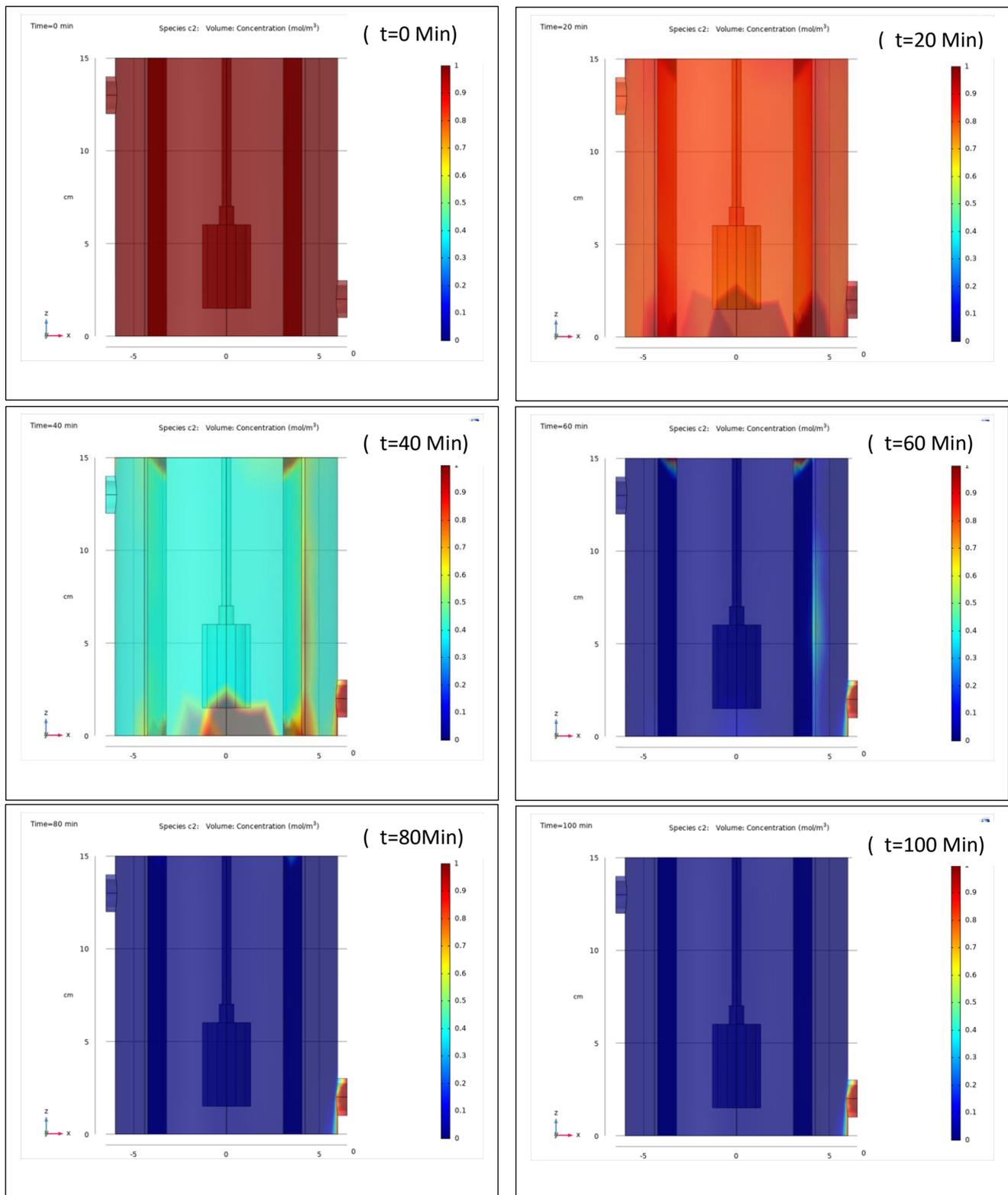


Figure (4.58) Lead distribution at HRT=30 min ,V=6V and rpm=50 .

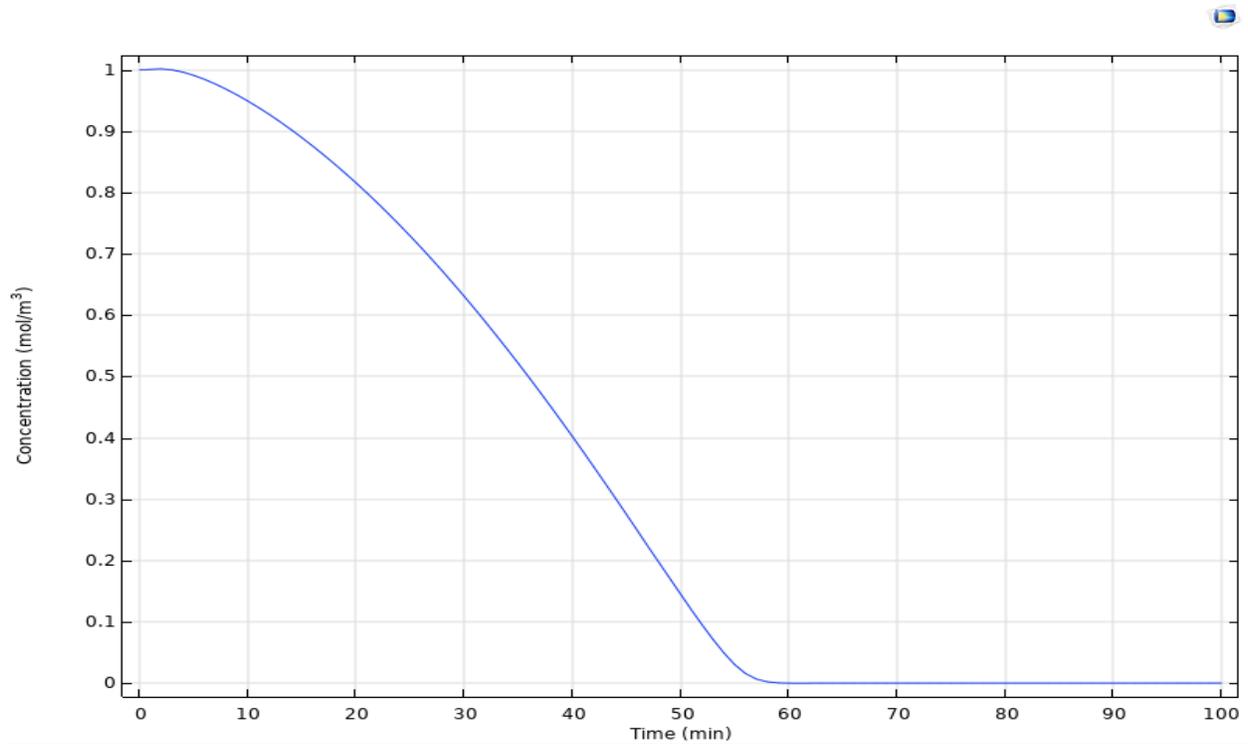


Figure (4.59) (Concentration of lead at.)at V=6V, HRT=30 min. and rpm=50.

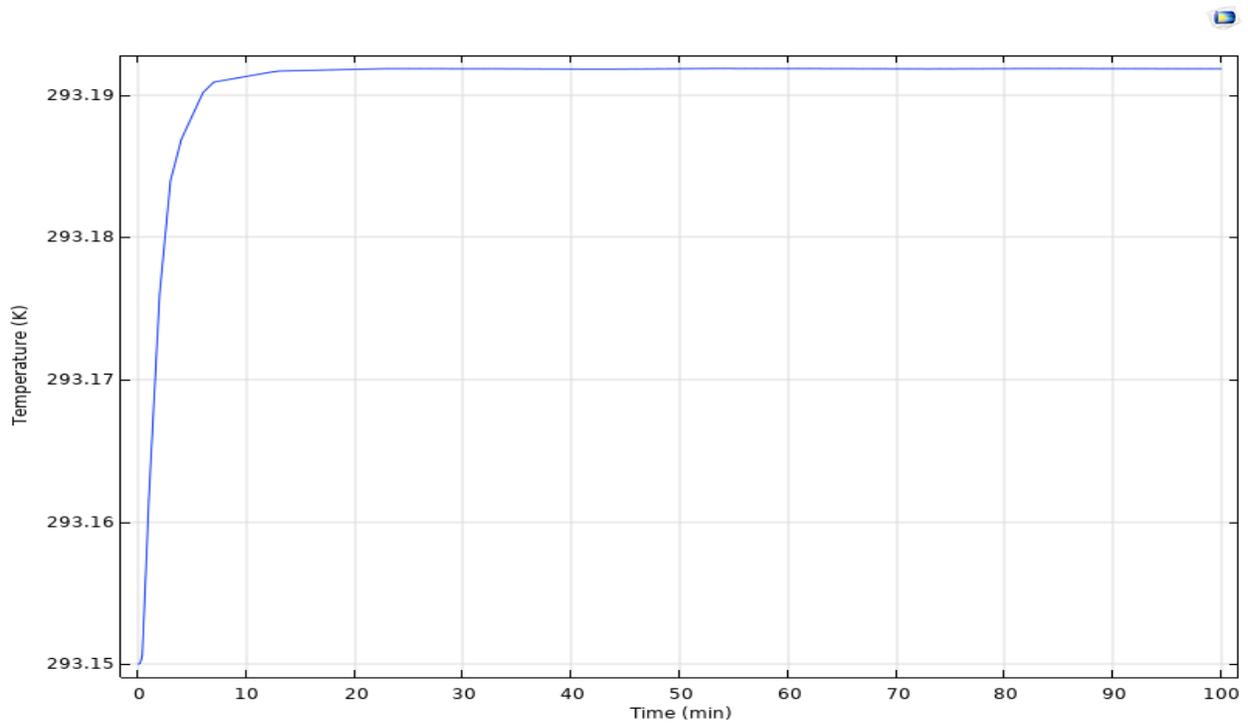


Figure (4.60) Temperature distribution of isothermal process at V=6V, HRT=30 min and rpm=50.

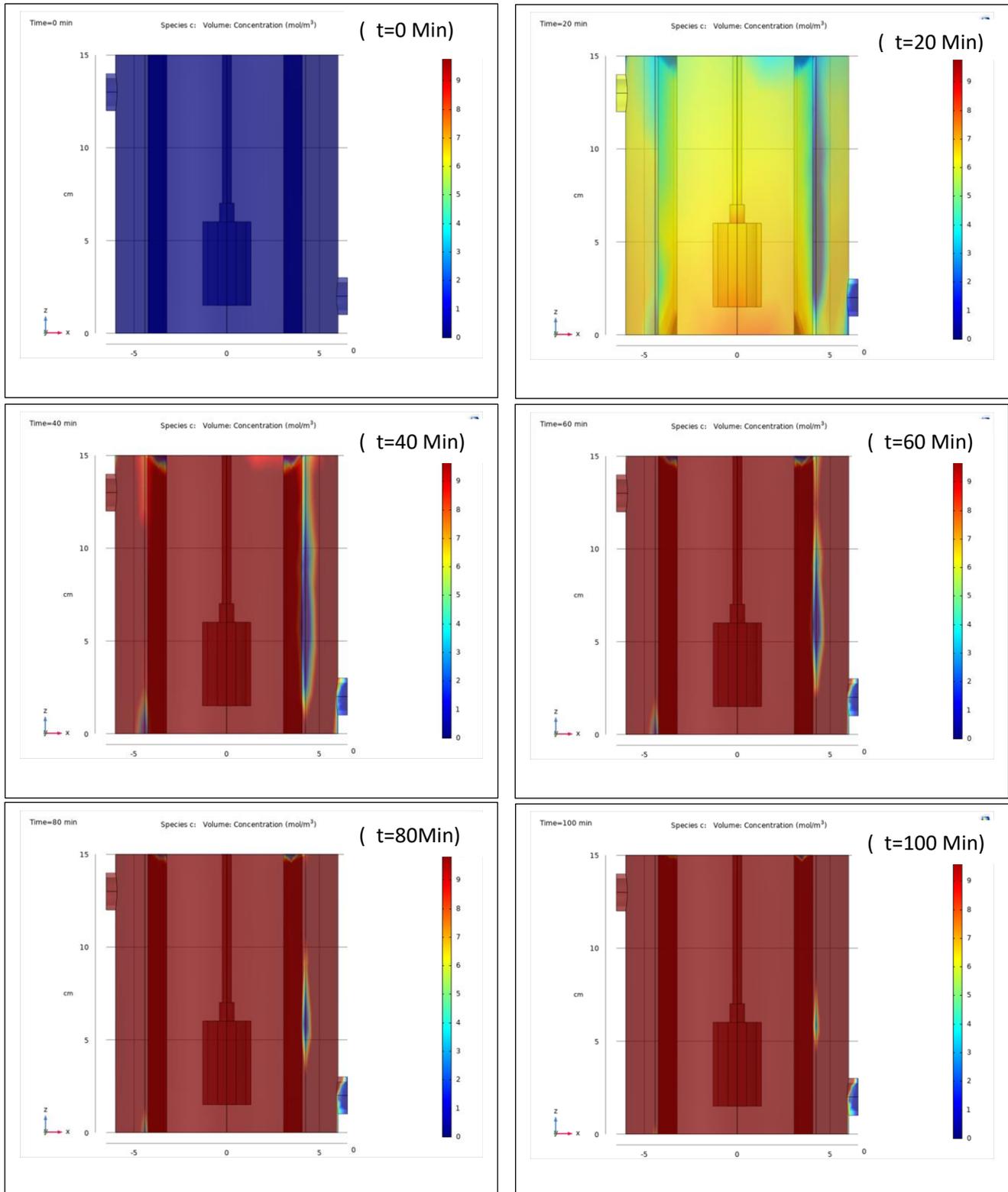
Non –Isothermal process .

Figure (4.61) Distribution of coagulants in the EC reactor at HRT=30 min ,V=6V and rpm=50 Non-isothermal.

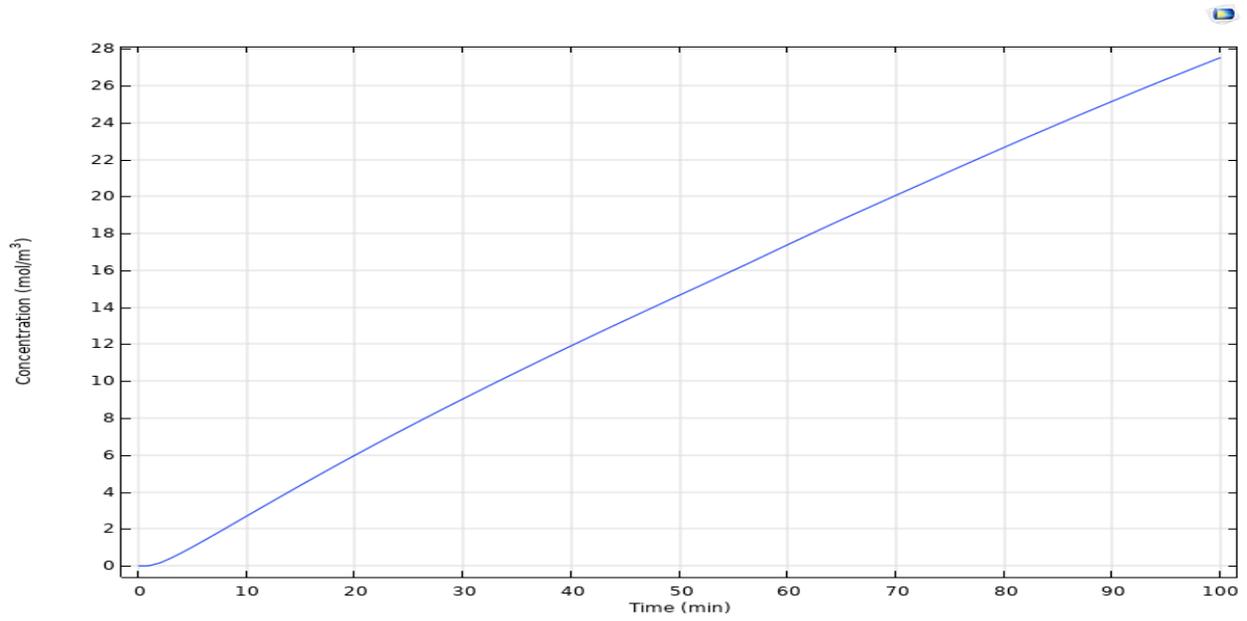
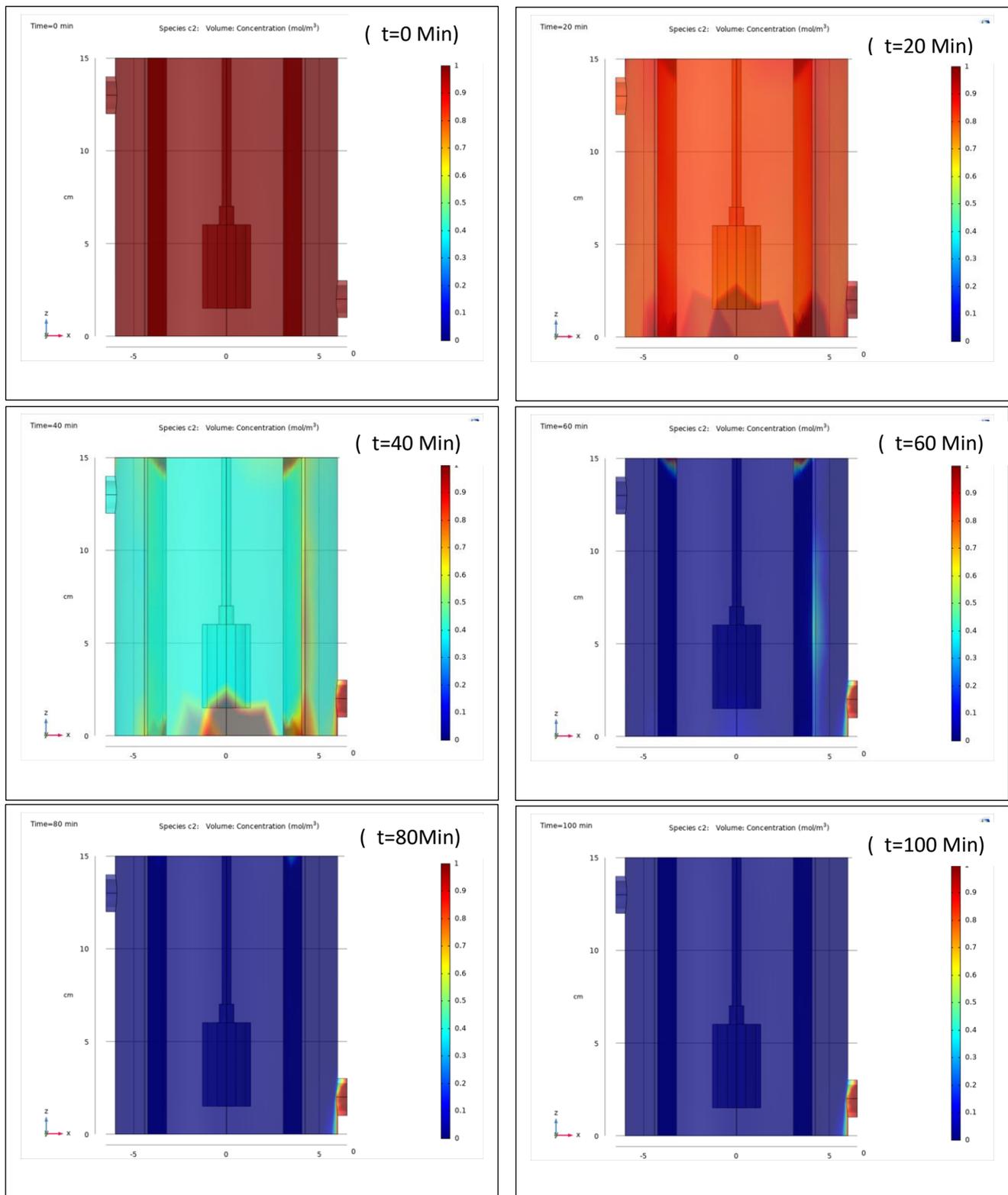


Figure (4.62) Coagulants concentration at $V=6V$, $HRT=30$ min and $rpm=50$.



Figure(4.63) Lead distribution at $V=6V$, $HRT=30$ min. and $rpm=50$ Non-isothermal.

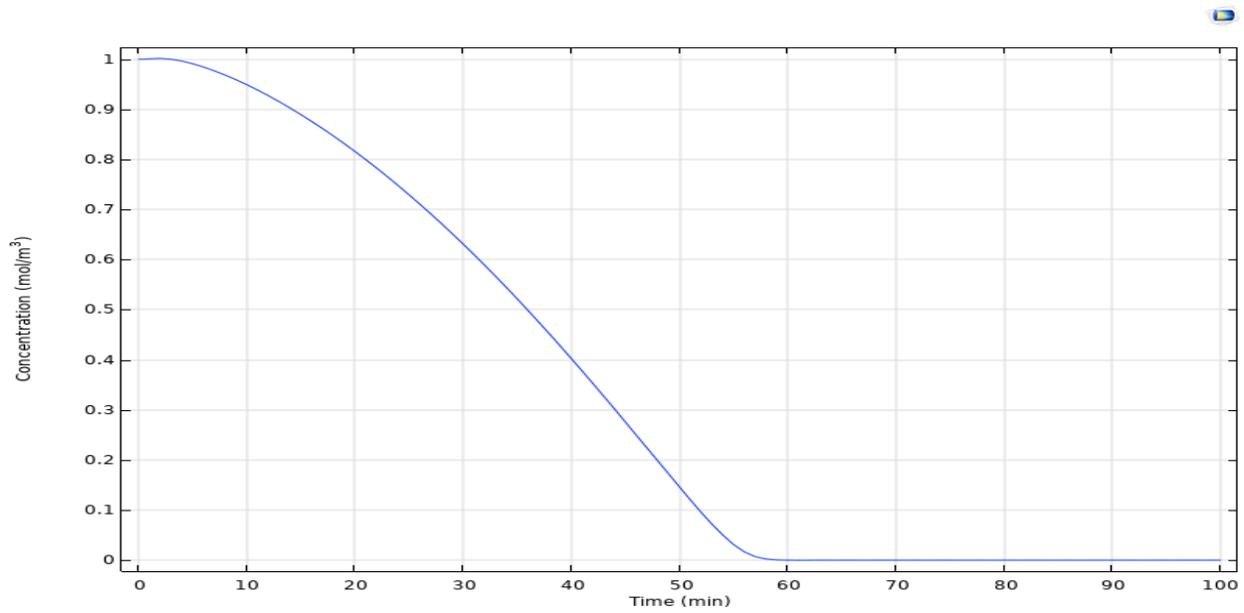


Figure (4.64) (Concentration of lead at V=6V, (HRT=30 min) and rpm=50.

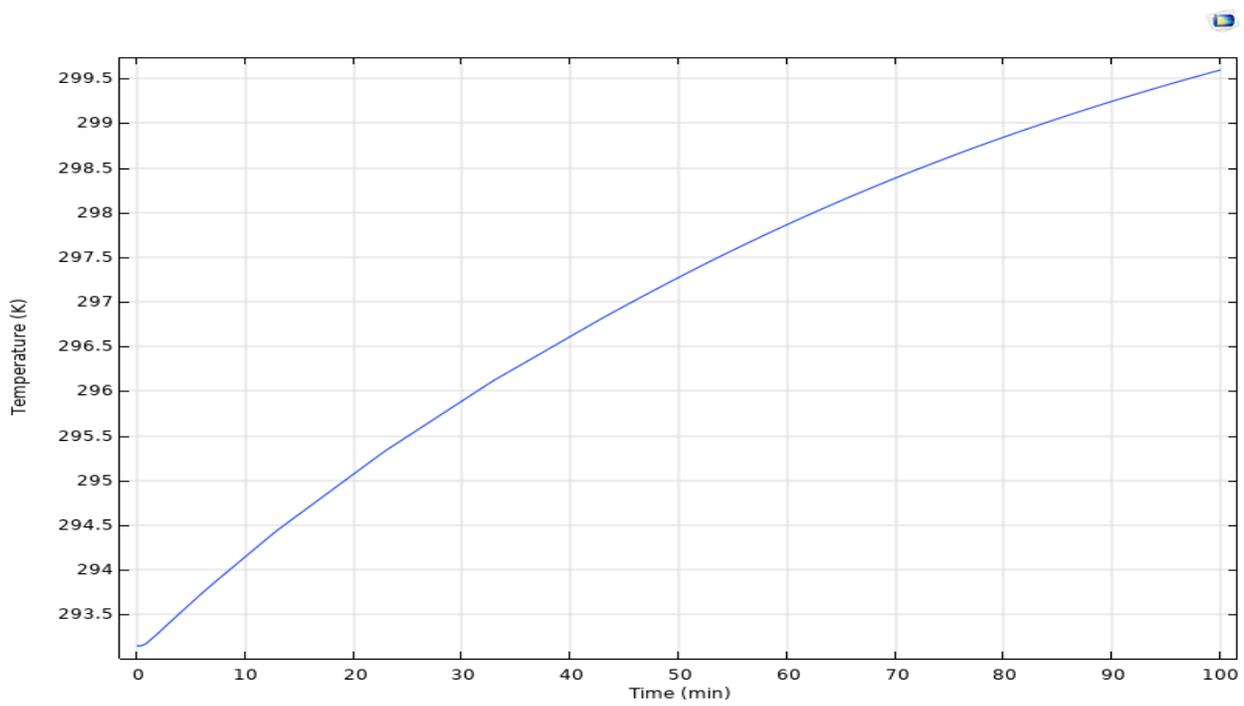


Figure (4.65) Temperature distribution at V=6V, (HRT=30 min) and rpm=50.

Chapter Five :Conclusion And Recommendations

5.1 CONCLUSION

The following are the inclusions from this research:

- Using software to simulate the EC process is effective method to predict the optimum condition ,then improve the process efficiently and accurately
- By using COMSOL multi-physics software to solve partial differential equation, concentration ,heat ,velocity ,voltage and current density have been simulated.
- The lead removal increase when ,applied voltage, current density , rotating, and time increasing, Lead removal increase with speed of rotation for the anode within limit, which is 50rpm beyond that the effect of rotational speed become negative .
- Coagulants increase when applied voltage, current density ,temperature , rotating, and time increasing .
- HRT neither effecting on the coagulants production nor lead concentration .
- With increasing the HRT the temperature increasing .
- The reaction very fast, so the temperature doesn't effect on the lead reaction removal .

5.2 RECOMENDATIONS

- Study the EC process with higher range of temperature .
- Increase the rotating anode speed more than 100 rpm.
- Study more parameters like pH and electrode material influence on the EC process.

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Appendix

properties of parameters that used in the model

i0_c	1e-6[A/cm ²]	Cathode exchange current density
Eeq_a	1.22[V]	Equilibrium anode potential
Eeq_c	0[V]	Equilibrium cathode potential
D_Al	5.41e-10[m ² /s]	Diffusion coefficient of Al ion
D_Pb	9.45e-10[m ² /s]	Diffusion coefficient of Pb ion
Z_Al	3	Number of electrons transfer for Al
Z_Pb	2	Number of electrons transfer for Pb
Mw_Al	27	Molecular weight of Al
Mw_Pb	207.2	Molecular weight of Pb
c_ini(Al)	0	Initial concentration of Al
c_ini(Pb)	1[mol/m ³]	Initial concentration of Pb
VOL	800[cm ³]	Volume of the solution
T0	293.15	Temperature

الخلاصة

تعتبر عملية التخثير الكهربائي (EC) احد اهم الطرق لتنقية المياه الملوثة ومياه الشرب نظرًا للجدوى الاقتصادية ، فهي سهلة البناء والتشغيل والصيانة واستهلاكها منخفض للطاقة. يتناول هذا البحث عملية EC بأخذ الحرارة بعين الاعتبار باستخدام ديناميكية السوائل الحسابية (CFD) لمحاكاة العملية. الملوث هو الرصاص بتركيز أولي 1 مول / م 3 ، والبرنامج هو COMSOL MULTIPHSYSICS 5.5 لحل المعادلات التفاضلية. واحدة من أكثر المتغيرات تأثيرًا هي الجهد المسلط ، حيث تؤدي زيادة الجهد المسلط إلى زيادة كثافة التيار ودرجة حرارة العملية ، ثم يؤدي إلى تحسين إزالة الرصاص. يعمل الأنود المتحرك أيضًا على تحسين إزالة الرصاص ، ضمن الحد الأعلى الذي هو في هذه الحالة 50 دورة في الدقيقة ، بعد هذا الحد تصبح كفاءة الإزالة سلبية. الفولتية المسلطة المستخدمة في هذا البحث هي 6،3،1.5 و 10 فولت. سرعات الدوران 0،10،50 و 100 دورة في الدقيقة. يأخذ البحث التيار والجهد المسلط في الحالة المستقرة اما التركيز و درجة الحرارة الحالة المعتمدة على الوقت, أخذًا ستة أوقات مختلفة لكل حالة من الحالات ، 0،20،40،60،80 دقيقة. للمقارنة بينهم ، ثم استنتاج النتيجة لدراستها. أثبتت النتيجة أن التخلص من الملوثات يزداد عند زيادة الجهد المسلط والوقت وسرعة دوران الأنود ، وأظهرت النتائج زيادة تركيز المواد المخثرة مع زيادة الجهد المسلط وبالتالي زيادة تركيز المخثرات وزيادة كفاءة إزالة الرصاص أيضًا. تأثير سرعة الدوران يأتى ايجابيا ضمن الحدود القصوى لسرعة الدوران وهي 50 دورة في الدقيقة بعد هذه السرعة ، يصبح زيادة سرعة الدوران سلبيا. تمت دراسة HRT ، وأظهرت النتائج أن تأثيره يؤثر بشكل طفيف جدا مقارنة مع المتغيرات الأخرى ، تم أخذ (10) HRT ، (20، 30 و 40 دقيقة) تظهر النتيجة أن HRT لا يؤثر على المخثرات وتركيز الرصاص بينما تزداد درجة الحرارة مع زيادة HRT . تم استخدام رسومات ومخططات CMOSOL لتوضيح النتائج. أظهرت النتائج أن الوقت اللازم لإزالة الملوثات الكاملة يتناقص مع الفولتية المطبقة والتيار وسرعة الدوران حتى 50 دورة في الدقيقة. افترض البحث أن نطاق العمل في 3 D ، التدفق مستقر ، اخذ الحرارة بعين الاعتبار ، السائل النيوتوني ، التيار والجريان الحالة الثابتة ، التركيز والحرارة معتمدة على الوقت.



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وزارة التعليم العالي والبحث العلمي
جامعة بابل- كلية الهندسة
قسم الهندسة الكيمياءوية

ديناميكية الجريان العددية لمحاكاة التبخير الكهربائي الحراري

رسالة

مقدمة الى كلية الهندسة في جامعة بابل وهي جزء من متطلبات نيل الماجستير في
الهندسة/ الهندسة الكهروكيمياوية

من قبل

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إشراف

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2022