CHAPTER 3

RESULTS AND DISCUSSIONS OF MATHEMATICAL MODEL OF BIPOLAR PLATES FOR (PEMFC)

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3.1 INTRODUCTION

In this chapter, the bipolar plates (BPPs) model of PEMFC has been developed based on mathematical model discussed in the previous chapter; this chapter aims to study different designs of bipolar plate to obtain the best design which will be used in PEMFC to realize optimum PEMFC performance. .

3.2 RESULTS AND DISCUSSION

3.2.1 Parallel or straight bipolar plate

Figure (3.1) shows two dimension designs for parallel or straight bipolar plate with 1 mm width, 1 mm depth and 1 mm rip and number of channels 54 straight and parallel channels. Figure (3.2 a) Shows pressure distribution for parallel or straight bipolar plate for air at flow velocity 0.2 m/s as the pressure at inlet is 10.794 Pa and at the outlet is 0.0895 Pa . Figure (3.2 b) Shows pressure distribution for H_2 as the pressure at inlet is 5.1717 Pa and at the outlet is 0.0443 Pa. Effective area is 5671 mm^2 and pressure drop 5.17 Pa, the pressure distribution is homogenous through the channels.

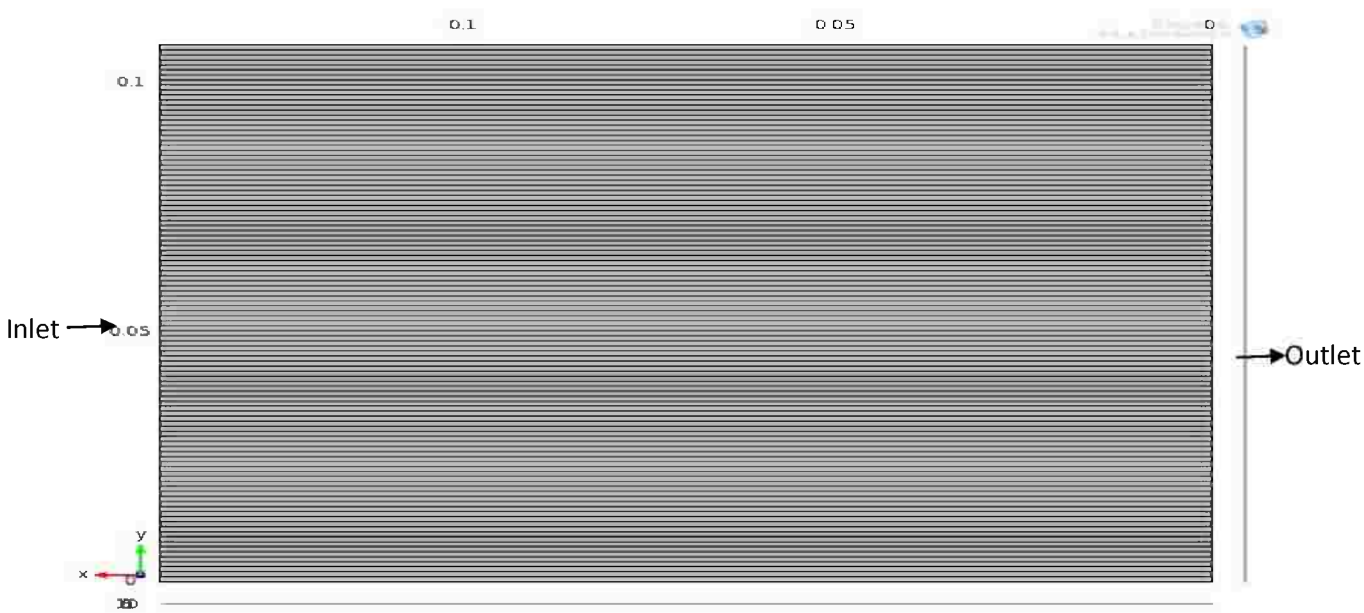
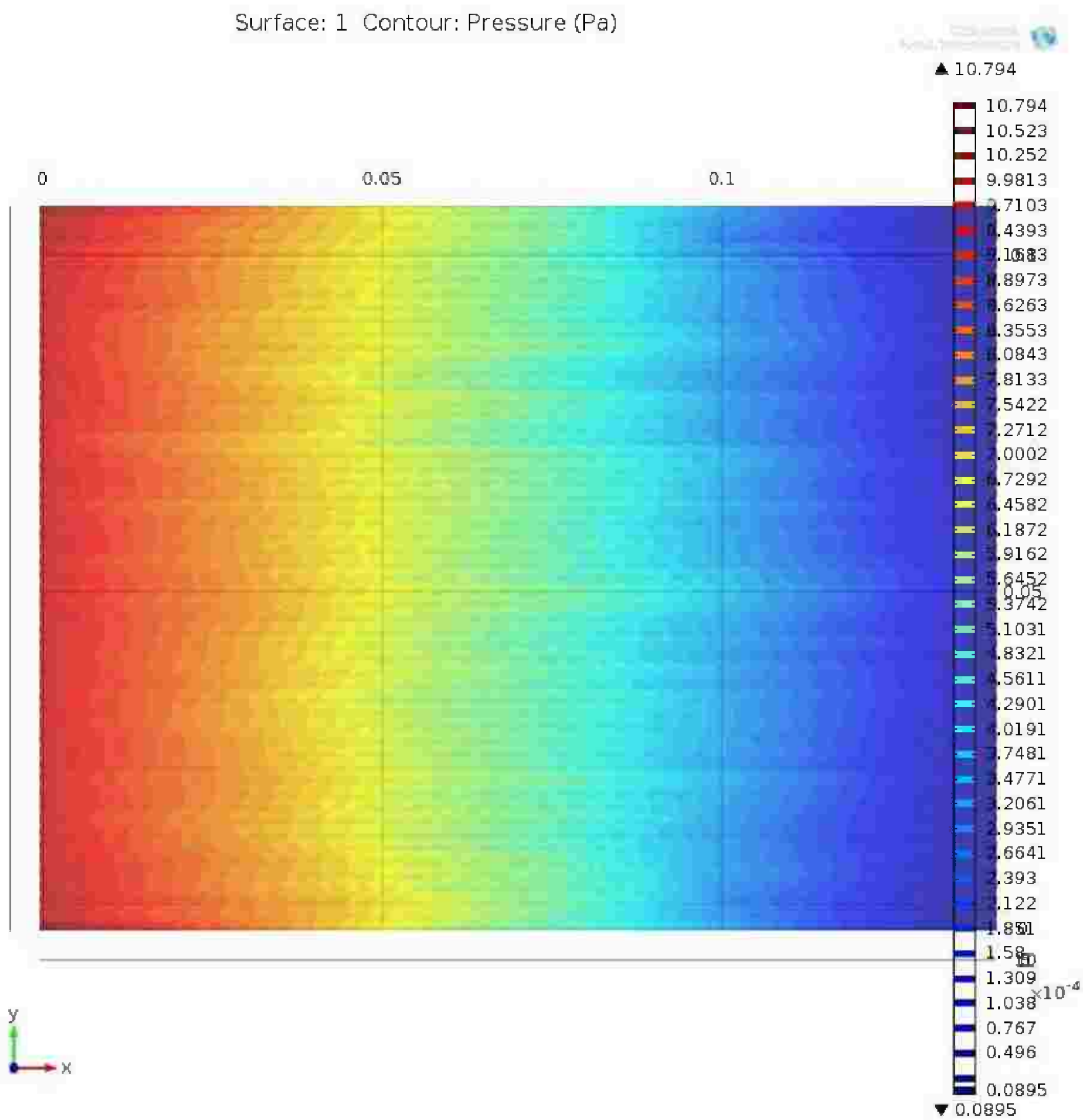
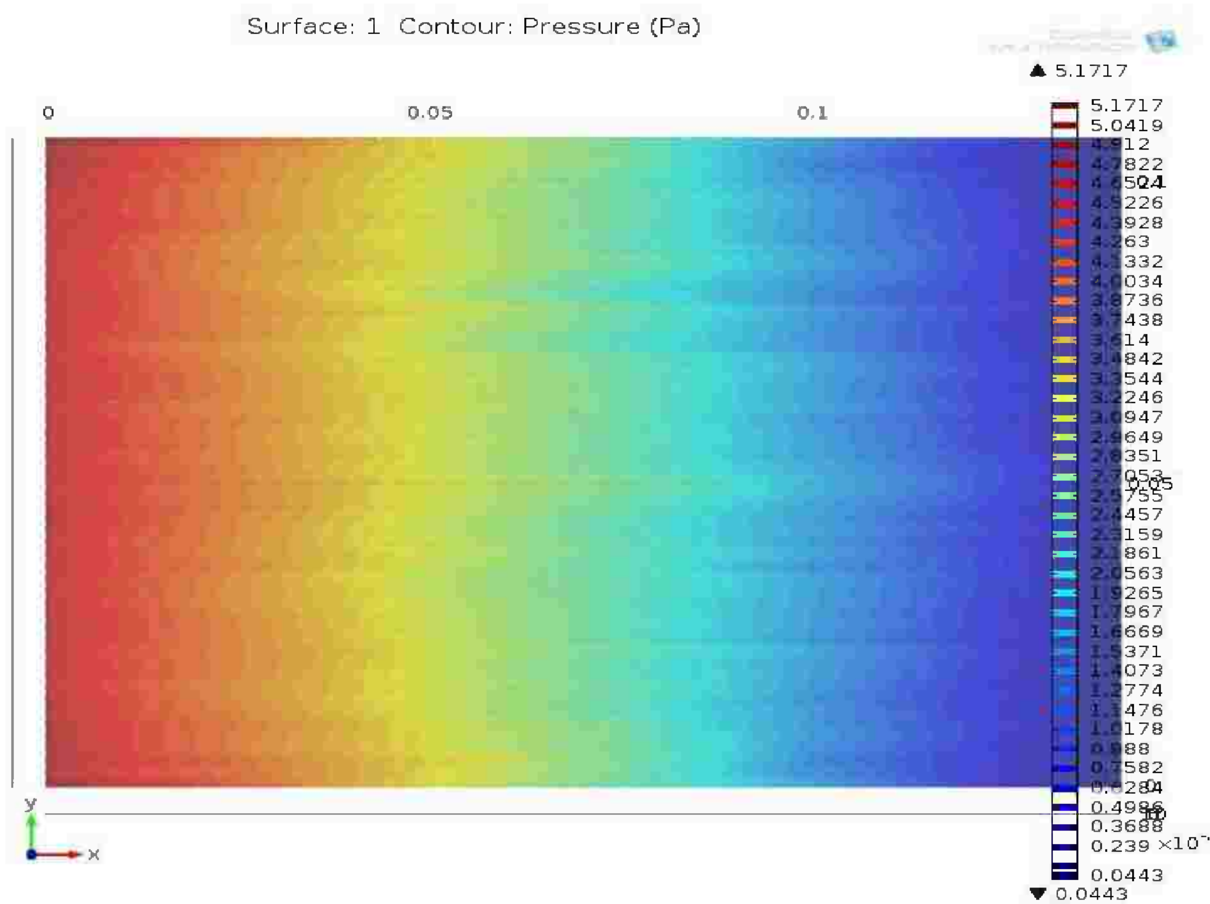


Figure 3.1 2D design for parallel or straight bipolar plate.


Surface: 1 Contour: Pressure (Pa)
▲ 10.794
10.794
10.523
10.252
9.9813
0
0.05
0.1
y
x
1.309
1.038
0.767
0.496
0.0895
×10⁻⁴
▼ 0.0895

(a)



(b)

Figure 3.2 Contour plot for parallel or straight bipolar plate at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.2 Header serpentine

3.2.2.1 Dual passes header serpentine

Figure (3.3) demonstrates two dimension designs for dual channel header serpentine with 1 mm width, 1 mm depth and 1 mm rip and number of passes are two and totally number of channels in this design is 54 parallel channels. Figure (3.4) shows pressure distribution for dual channel header serpentine at flow velocity 0.2m/s. In Figure (3.4 a) the working fluid is air as the pressure at inlet is 3860.4 Pa and at the outlet is 0.1605 Pa. Effective area is 5880 mm^2 and pressure drop 3860.2 Pa, the pressure distribution is homogenous through the channels, in Figure (3.4 b) the working fluid is H_2 as the pressure at inlet is 1646.9Pa and at the outlet is 0.0458 Pa. Effective area is 5880 mm^2 and pressure drop 1646.8 Pa, the pressure distribution is homogenous through the channels.

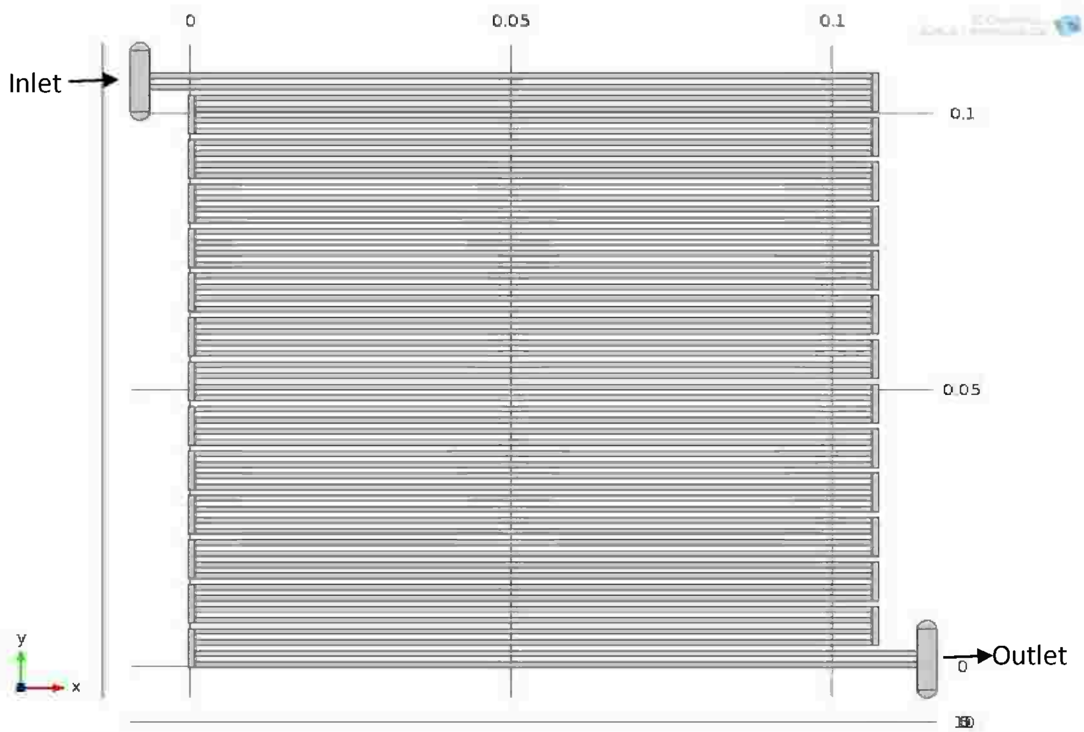
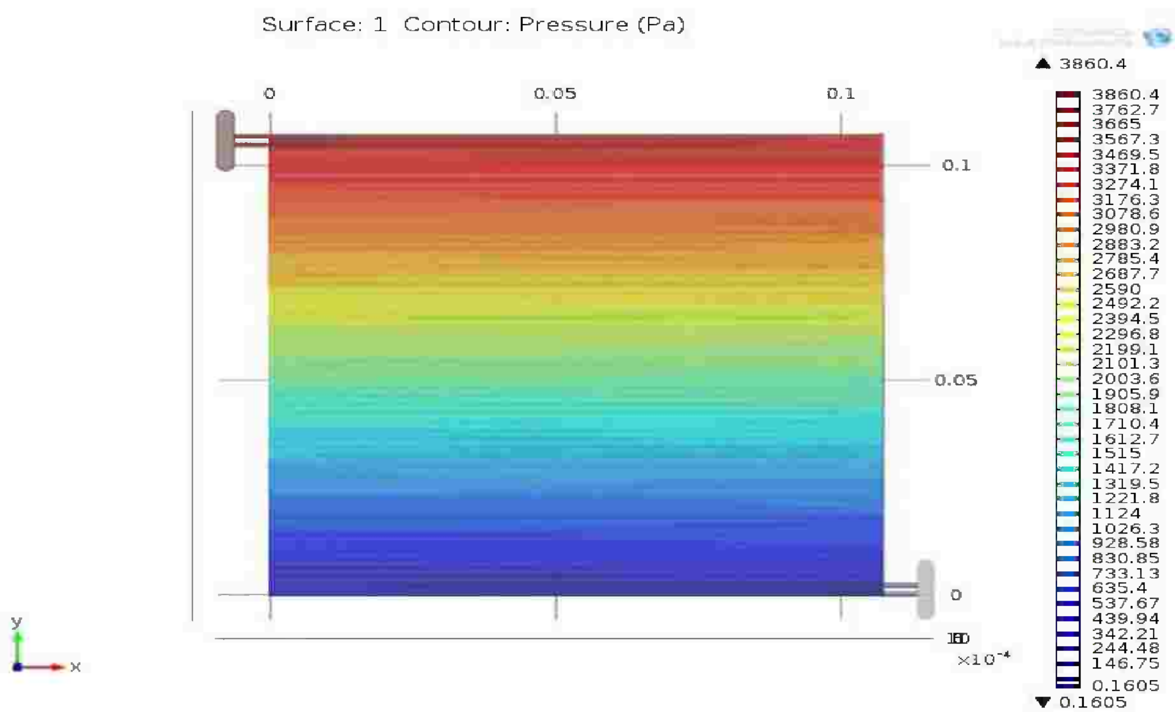
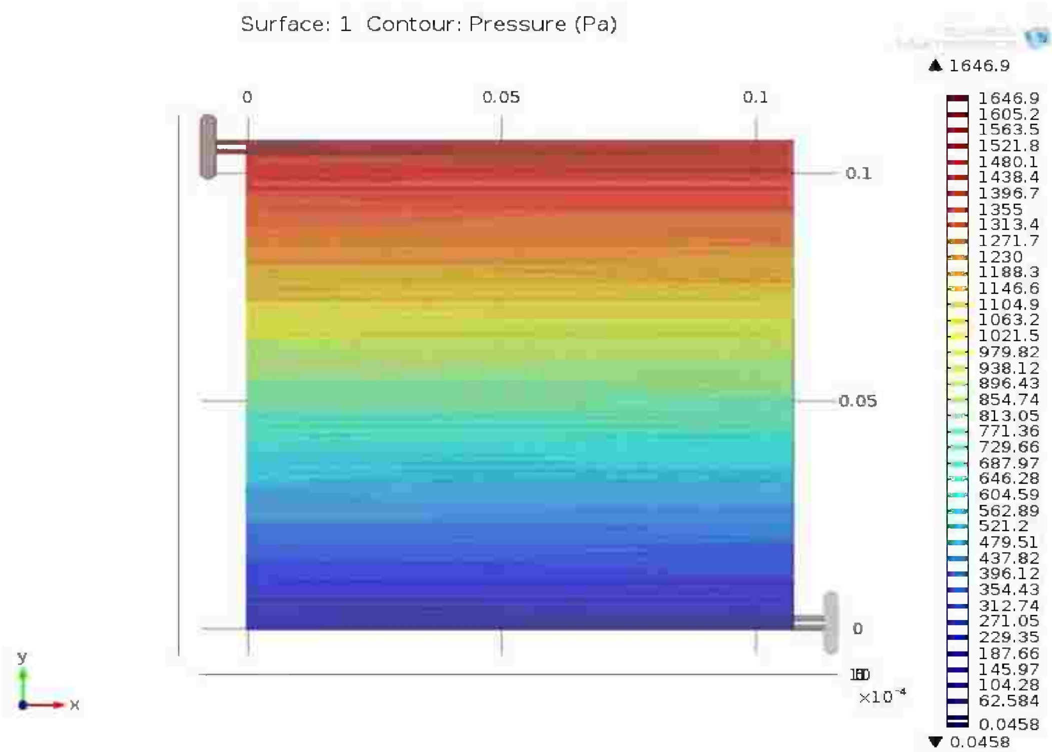


Figure 3.3 2D design for dual channel header serpentine.



(a)



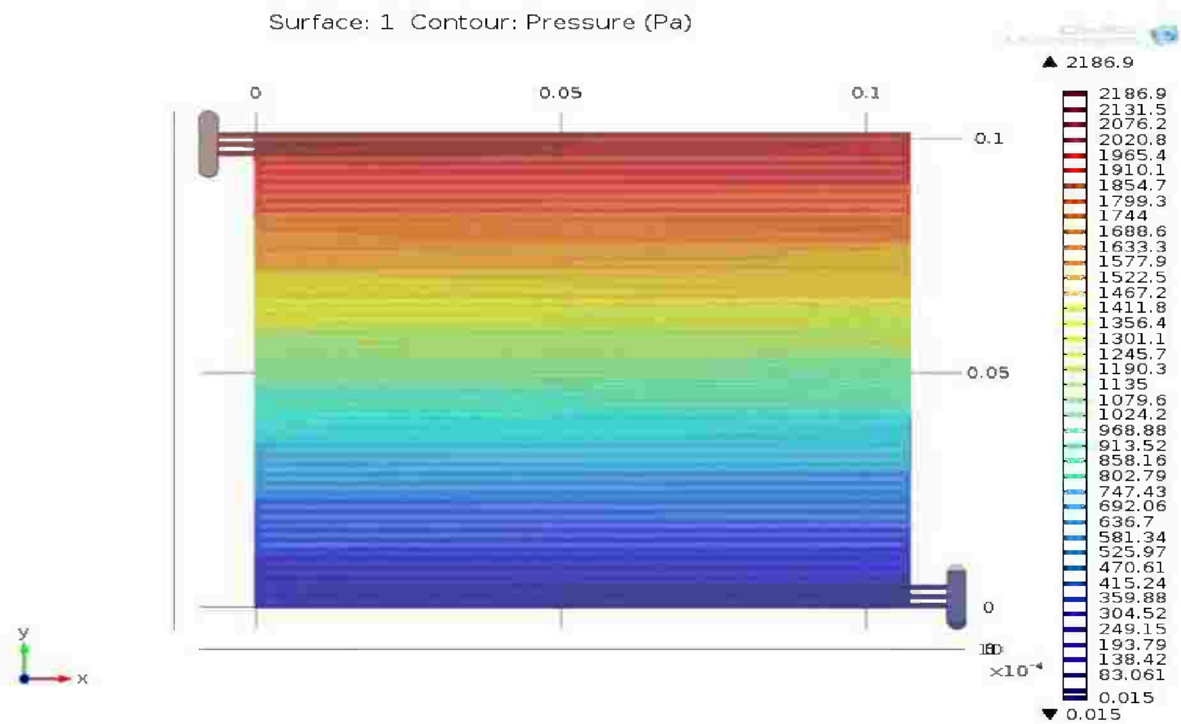
(b)

Figure 3.4 Contour plot for dual channel header serpentine at flow velocity 0.2 m/s (a) For air, (b) For H_2.

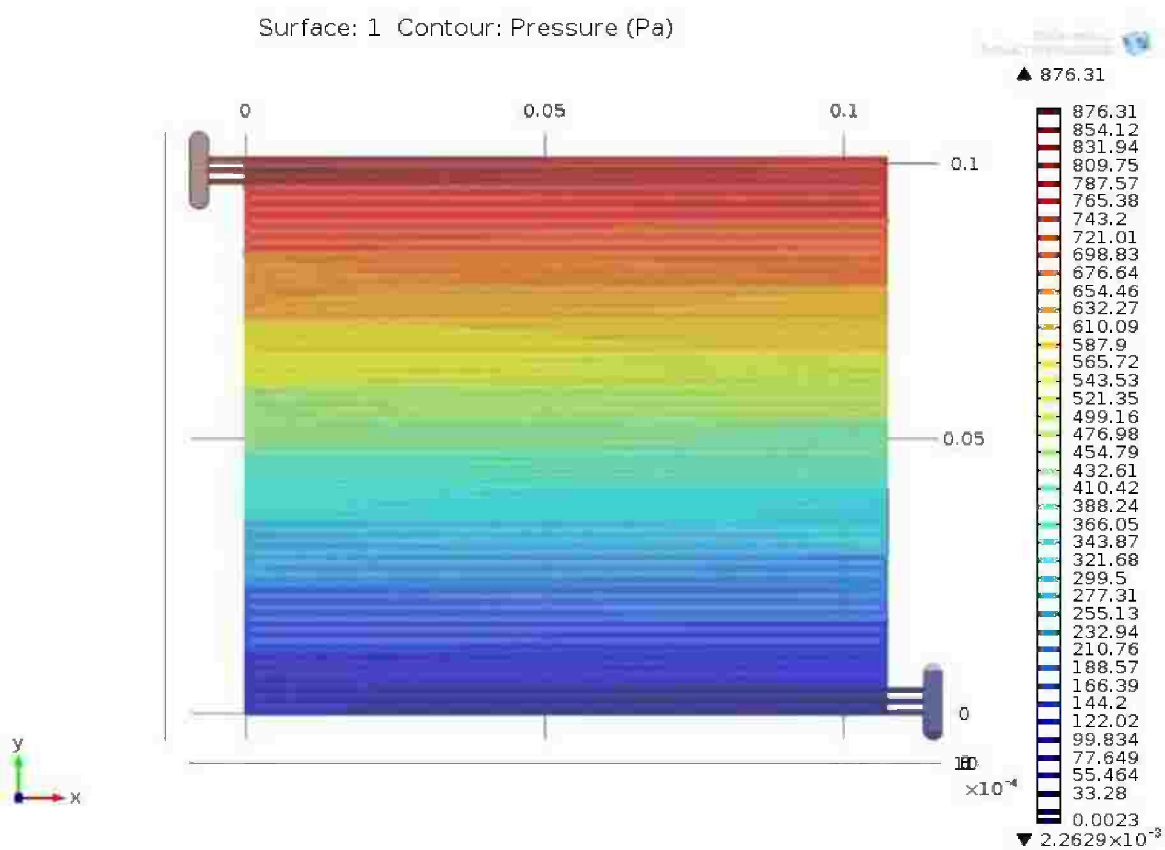
3.2.2.2 Triple passes header serpentine

Figure (3.5) observed two dimension designs for triple channel header serpentine with 1 mm width, 1 mm depth and 1 mm rip and number of passes are three and totally number of channels in this design is 51 parallel channels. Figure (3.6) shows pressure distribution for triple channel header serpentine at flow velocity 0.2 m/s. In Figure (3.6 a) the working fluid is air as the pressure at inlet is 2186.9 Pa and at the outlet is 0.015 Pa. Effective area is 5573 mm^2 and pressure drop 2186.7 Pa, the pressure distribution is homogenous through the channels, In Figure (3.6 b) the working fluid is H_2 as the pressure at inlet is 876.31 Pa and at the outlet is 0.0023 Pa. Effective area is 5573 mm^2 and pressure drop 876.3 Pa, the pressure distribution is homogenous through the channels.

Figure 3.5 2D design for triple channel header serpentine



(a)



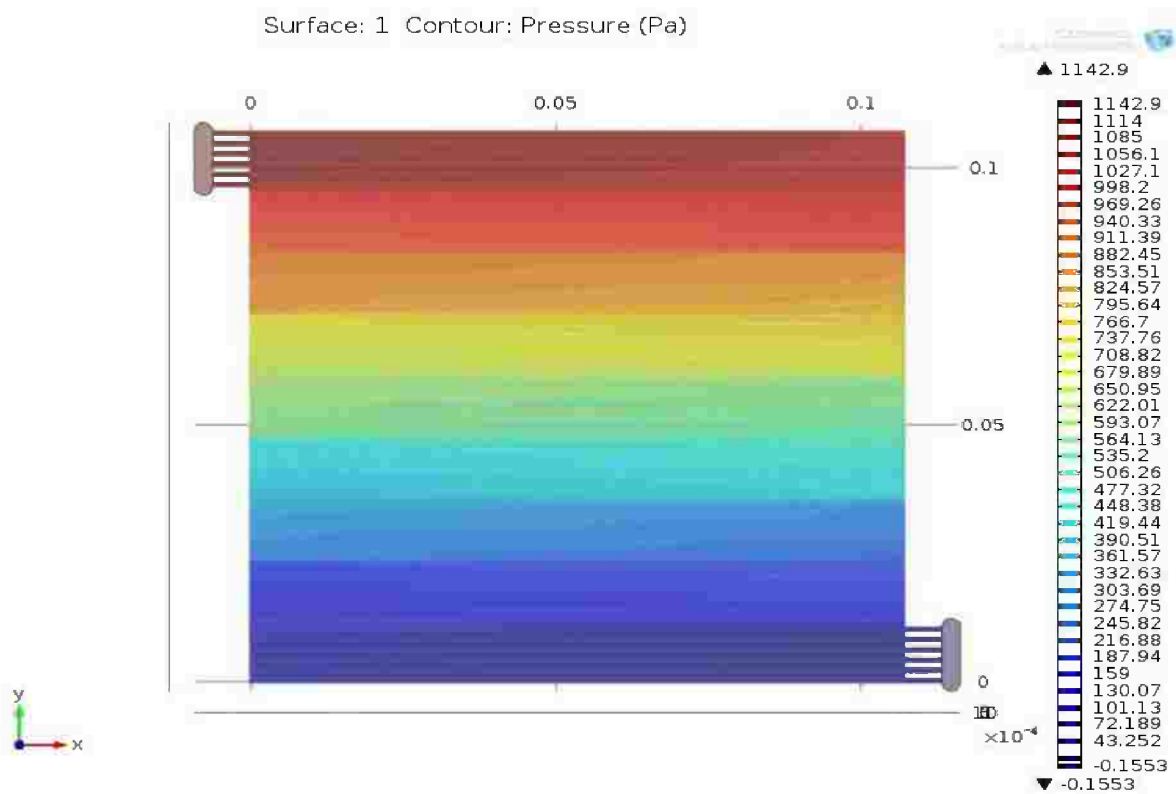
(b)

Figure 3.6 Contour plot for triple channel header serpentine at flow velocity 0.2 m/s (a) For air, (b) For H_2.

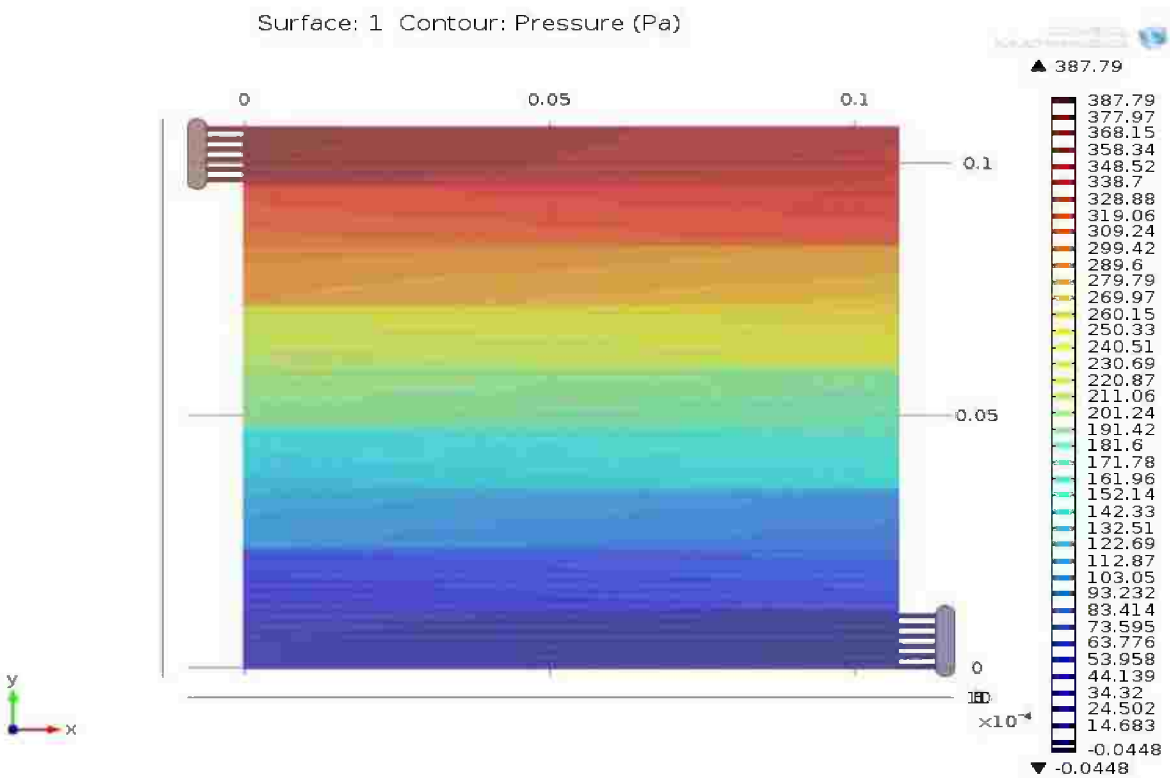
3.2.2.3 Six passes header serpentine

Two dimension designs for six channel header serpentine with 1 mm width, 1 mm depth and 1 mm rip and number of passes are six and totally number of channels in this design is 54 parallel channels is shown in Figure (3.7) .Figure (3.8) illustrates pressure distribution for six channel header serpentine at flow velocity 0.2 m/s. In Figure (3.8 a) the working fluid is air as the pressure at inlet is 1142.9 Pa and at the outlet is 0.1553 Pa. Effective area is 5938 mm^2 and pressure drop 1142.7 Pa, the pressure distribution is homogenous through the channels, in Figure (3.8 b) the working fluid is H_2 as the pressure at inlet is 387.79 Pa and at the outlet is 0.0448 Pa. Effective area is 5938 mm^2 and pressure drop 387.75 Pa, the pressure distribution is homogenous through the channels

Figure 3.7 2D design for six channel header serpentine



(a)



(b)

Figure 3.8 Contour plot for six channel header serpentine at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.3 Serpentine flow channels with square bend

3.2.3.1 Dual passes serpentine flow channels with square bend

Figure (3.9) illustrates two dimension designs for dual serpentine flow channels with square bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is two and totally number of channels in this design is 54 parallel channels. Figure (3.10) shows pressure distribution for dual serpentine flow channels with square bends at flow velocity 0.2 m/s. In Figure (3.10 a) the working fluid is air as the pressure at inlet is 3695.2 Pa and at the outlet is 0.0226 Pa. Effective area is 5854 mm^2 and pressure drop 3695.1 Pa, the pressure the pressure distribution is homogenous through the channels, in Figure (3.10 b) the working fluid is H_2 as the pressure at inlet is 1599.5 Pa and at the outlet is 0.0015 Pa. Effective area is 5854 mm^2 and pressure drop 1599.5 Pa, the pressure distribution is homogenous through the channels.

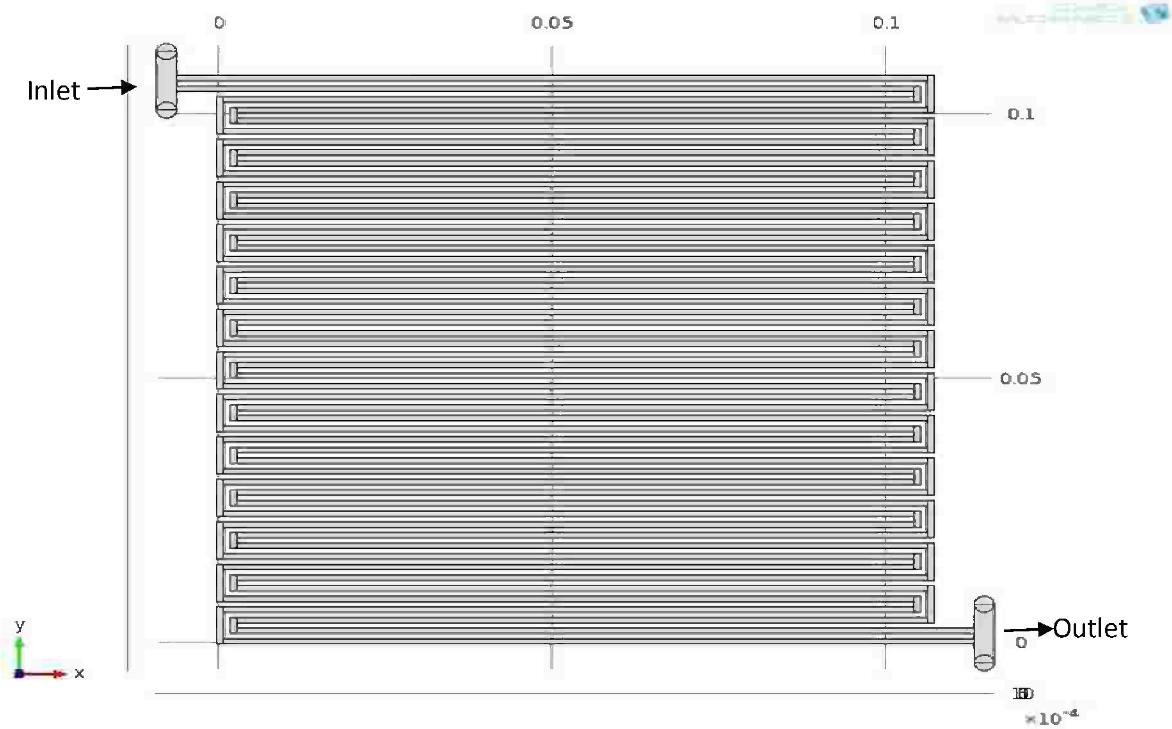
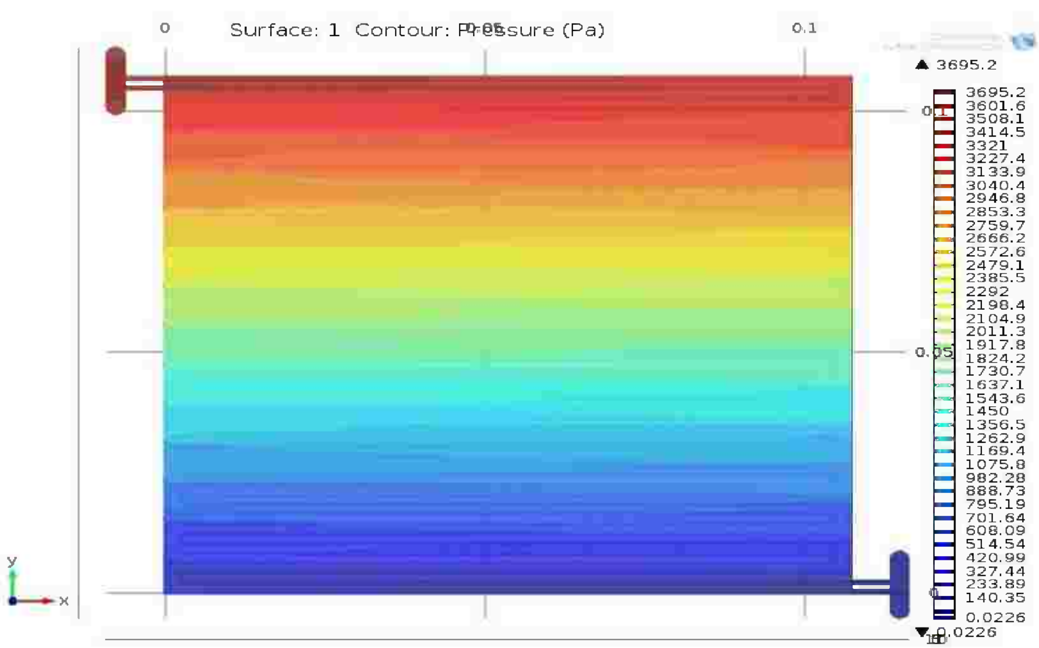
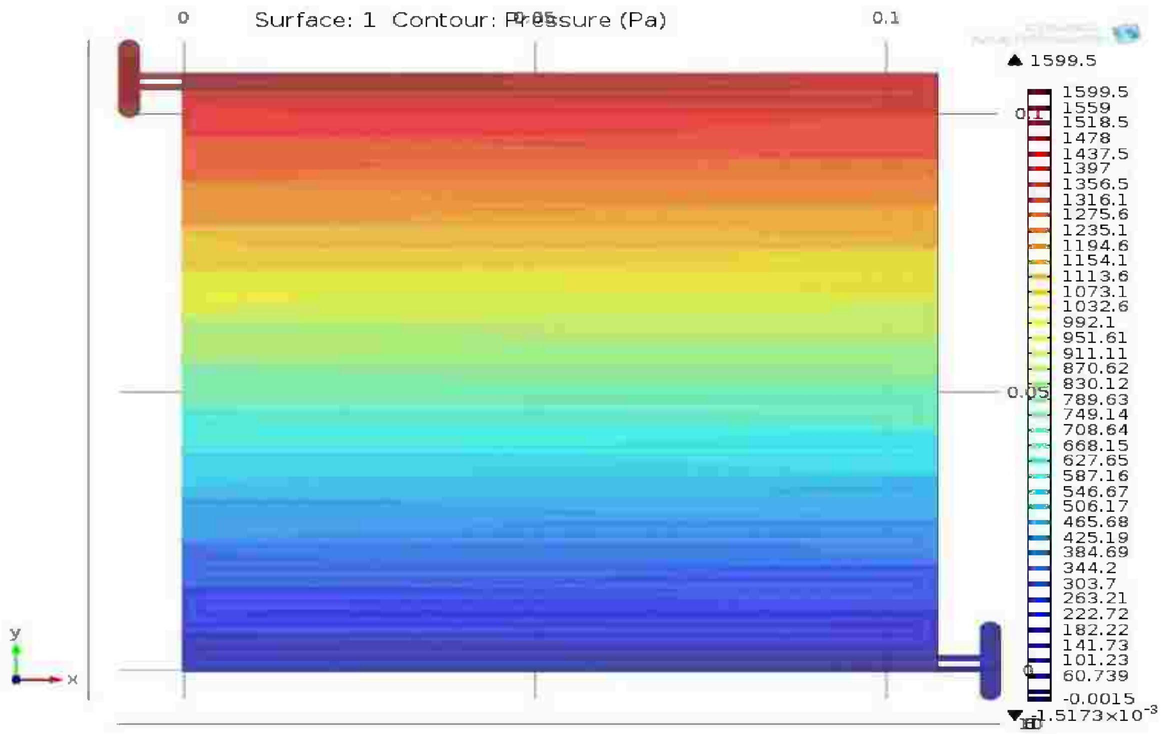


Figure 3.9 2D design for dual serpentine flow channels with square bend.



(a)



(b)

Figure 3.10 Contour plot for dual serpentine flow channels with square bend at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.3.2 Triple passes serpentine flow channels with square bend

Figure (3.11) demonstrates two dimension designs for triple serpentine flow channels with square bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is three and totally number of channels in this design is 51 parallel channels. Figure (3.12) shows pressure distribution for triple serpentine flow channels with square bends at flow velocity 0.2 m/s. In Figure (3.12 a) the working fluid is air as the pressure at inlet is 1737.6 Pa and at the outlet is 0.0154 Pa. Effective area is 5541 mm^2 and pressure drop 1737.6 Pa, the pressure distribution is homogenous through the channels, in Figure (3.12 b) the working fluid is H_2 as the pressure at inlet is 758.55 Pa and at the outlet is 0.0047 Pa. Effective area is 5541 mm^2 and pressure drop 758.55 Pa, the pressure distribution is homogenous through the channels.

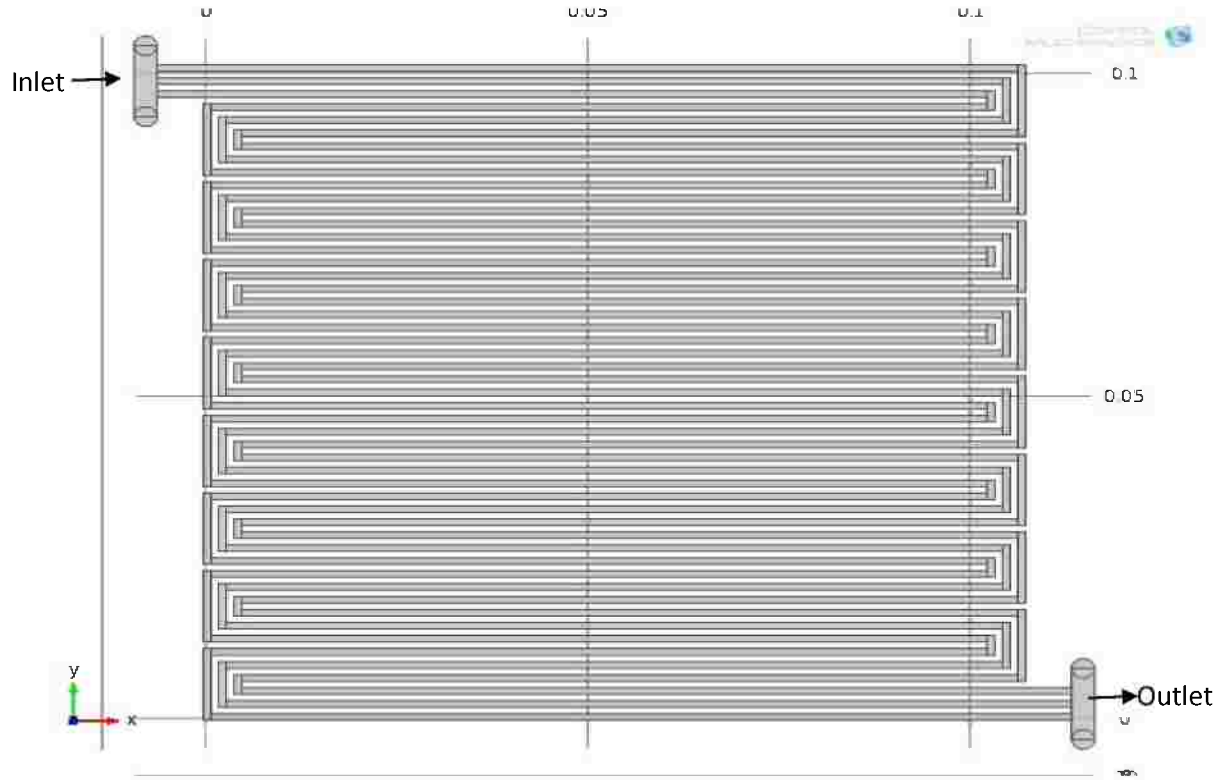
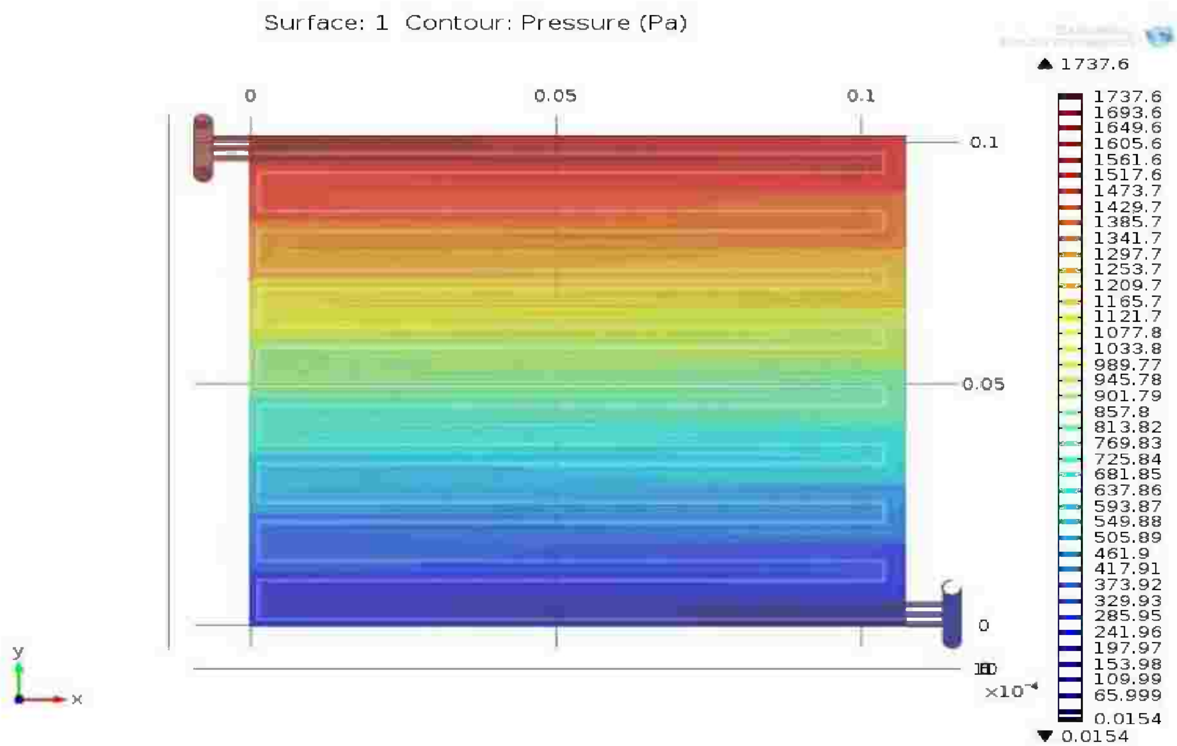
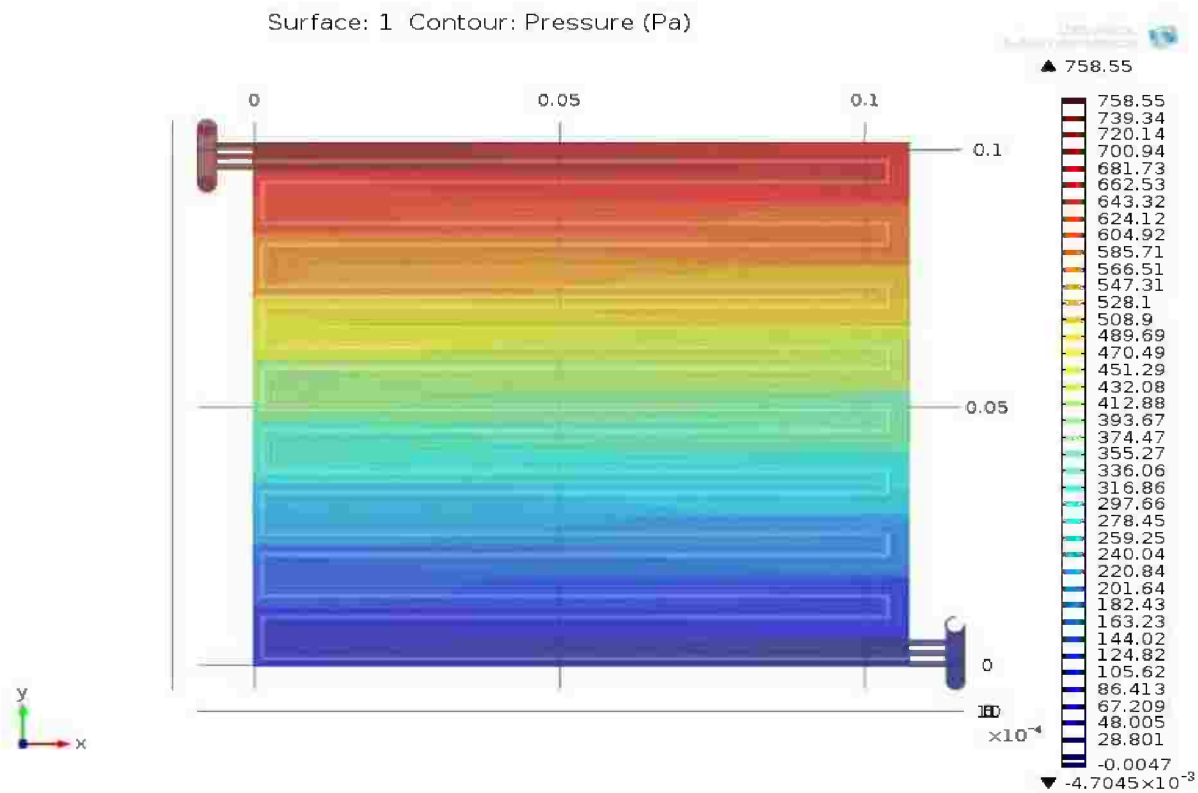


Fig 3.11 2D design for triple serpentine flow channels with square bend.



(a)



(b)

Fig 3.12 Contour plot for triple serpentine flow channels with square bend at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.3.3 Six passes serpentine flow channels with square bend

Figure (3.13) observes two dimension designs for six serpentine flow channels with square bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is six and totally number of channels in this design is 54 parallel channels. Figure (3.14) shows pressure distribution for sixth serpentine flow channels with square bends at flow velocity 0.2 m/s. In Figure (3.14 a) the working fluid is air as the pressure at inlet is 487.66 Pa and at the outlet is 0.0853 Pa. Effective area is 5898 mm^2 and pressure drop 487.66 Pa, the pressure distribution is homogenous through the channels, in Figure (3.14 b) the working fluid is H_2 as the pressure at inlet is 221.78 Pa and at the outlet is 0.0163 Pa. Effective area is 5898 mm^2 and pressure drop 221.78 Pa, the pressure distribution is homogenous through the channels.

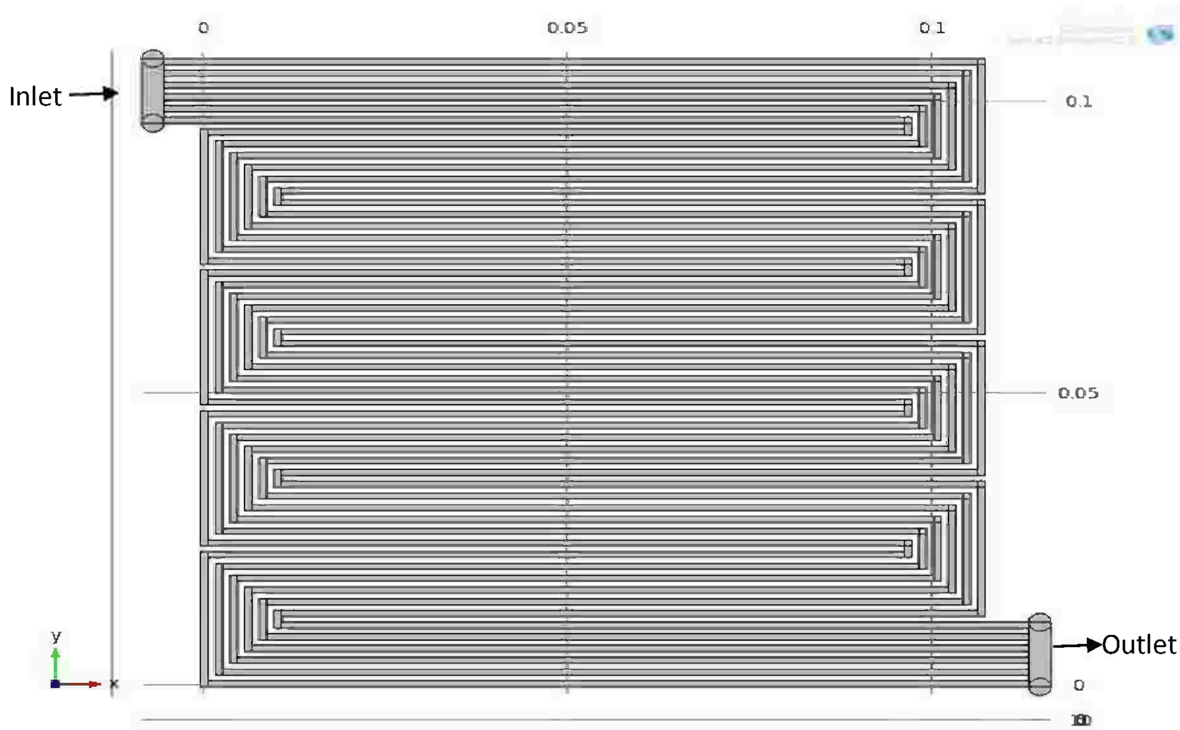
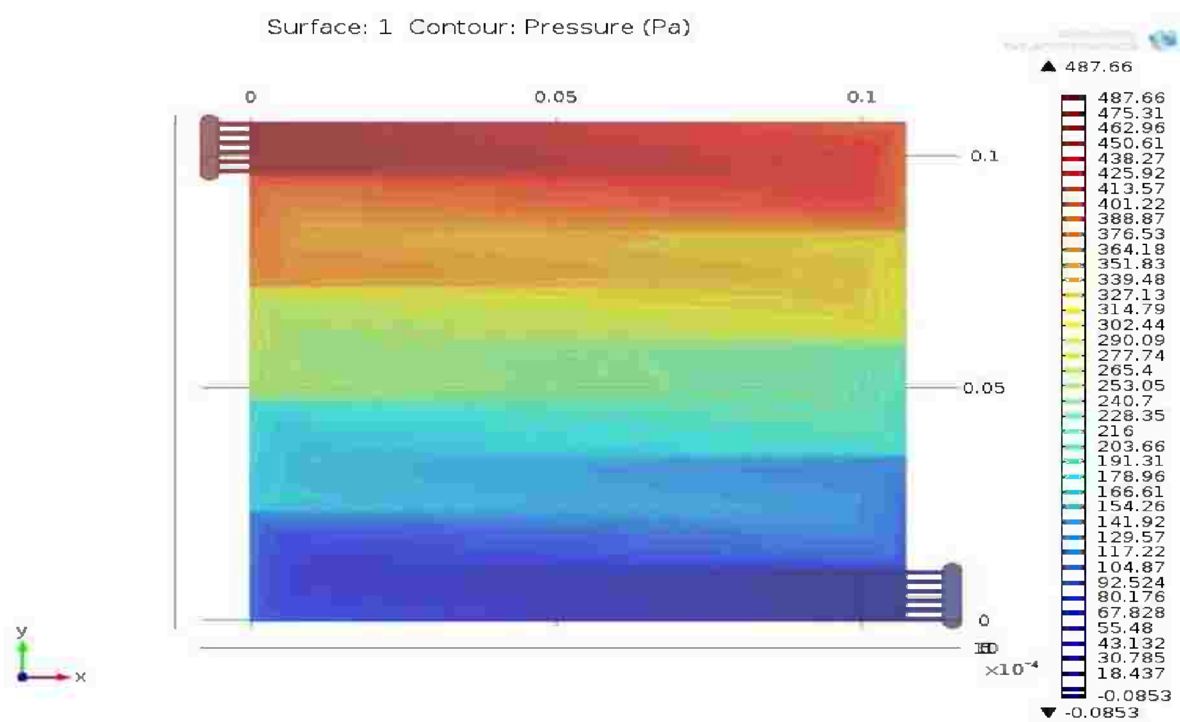
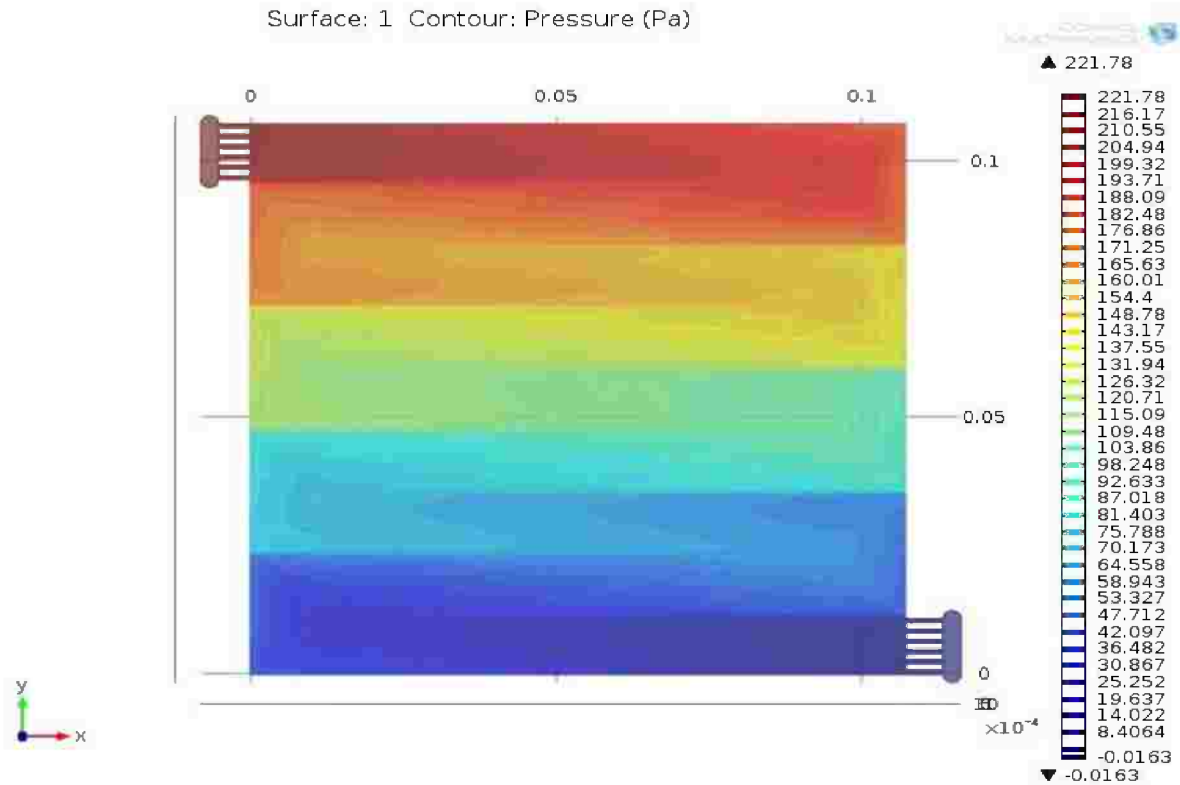


Figure 3.13 2D design for six serpentine flow channels with square bend.



(a)



(b)

Figure 3.14 Contour plot for six serpentine flow channels with square bend at flow velocity0.2 m/s (a) For air, (b) For H_2.

3.2.4 Serpentine flow channels with curvilinear bend

3.2.4.1 Dual passes serpentine flow channels with curvilinear bend

Figure (3.15) shows two dimension designs for dual serpentine flow channels with curvilinear bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is two and totally number of channels in this design is 54 parallel channels. Figure (3.16) demonstrates pressure distribution for dual serpentine flow channels with curvilinear bends at flow velocity 0.2 m/s. In Figure (3.16 a) the working fluid is air as the pressure at inlet is 1865.1 Pa and at the outlet is 0.0153 Pa. Effective area is 5714.7 mm^2 and pressure drop 1865.1 Pa, the pressure distribution is homogenous through the channels, in Figure (3.16 b) the working fluid is H_2 as the pressure at inlet is 897.24 Pa and at the outlet is 0.0032 Pa. Effective area is 5714.7 mm^2 and pressure drop 897.24 Pa, the pressure distribution is homogenous through the channels.

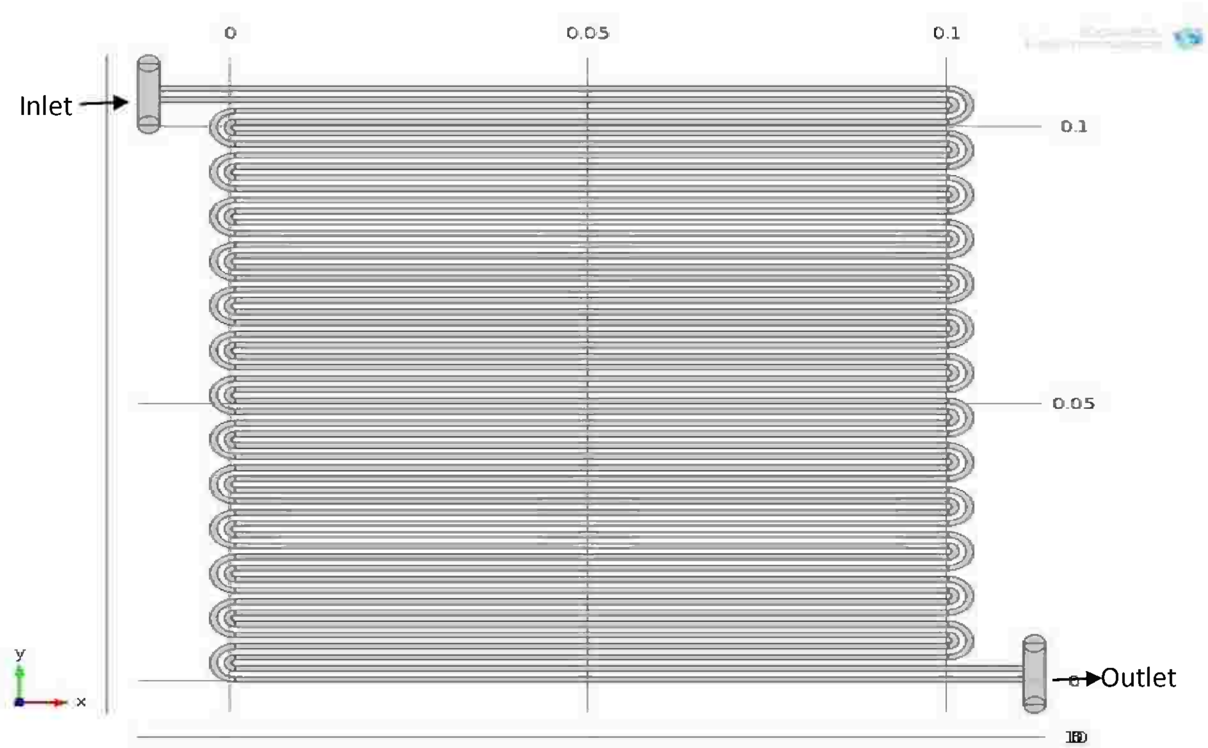
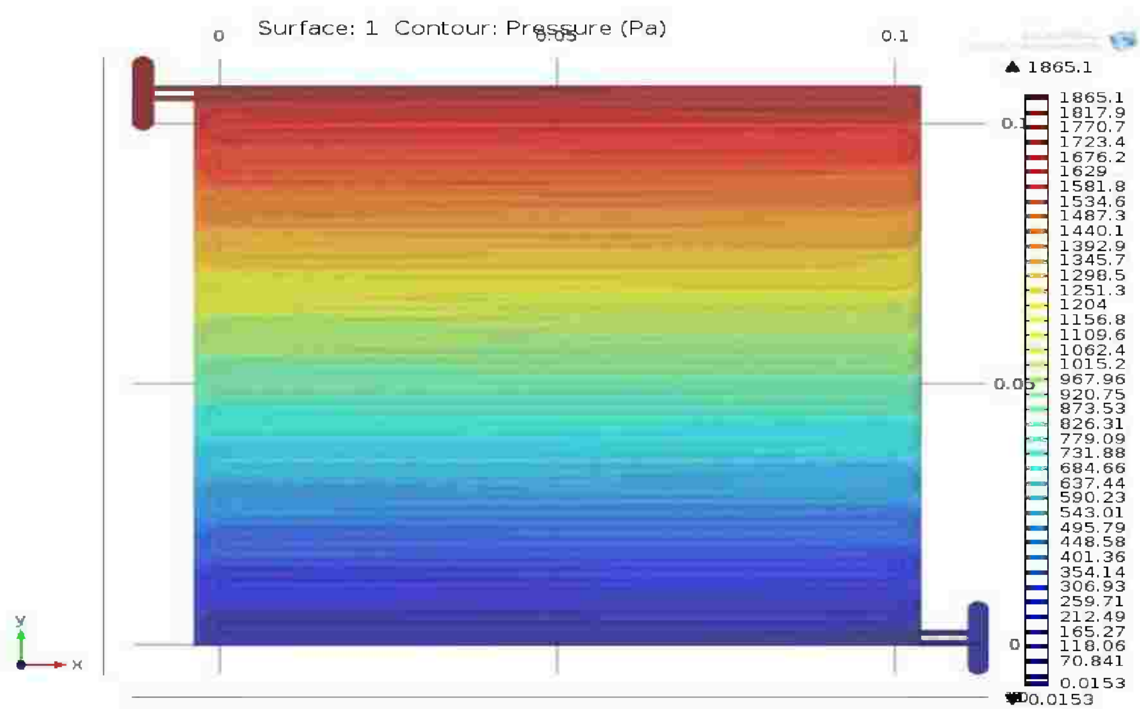
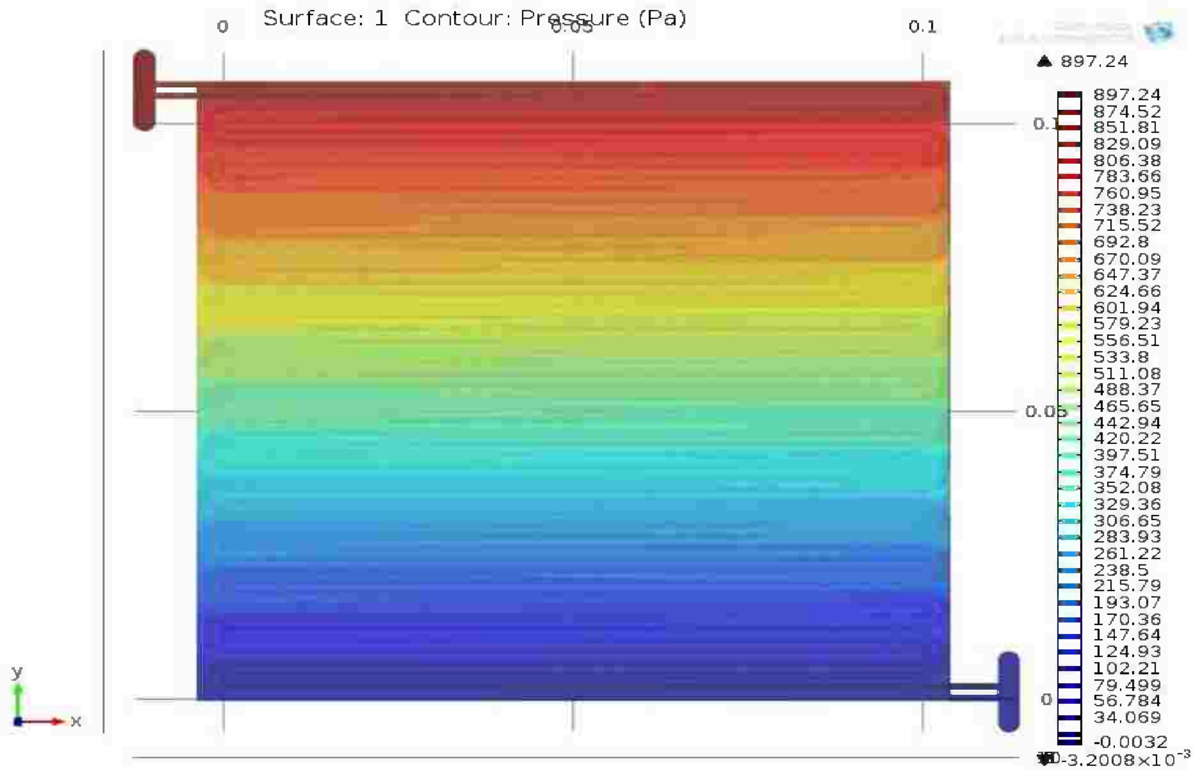


Fig 3.15 2D design for dual serpentine flow channels with curvilinear bend.



(a)



(b)

Figure 3.16 Contour plot for dual serpentine flow channels with curvilinear bend at flow velocity 0.2 m/s (a) For air, (b)For H_2.

3.2.4.2 Triple passes serpentine flow channels with curvilinear bend

Figure (3.17) illustrates two dimension designs for triple serpentine flow channels with curvilinear bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is three and totally number of channels in this design is 51 parallel channels. Figure (3.18) observes pressure distribution for triple serpentine flow channels with curvilinear bends at flow velocity 0.2 m/s. In Figure (3.18 a) the working fluid is air as the pressure at inlet is 1744.7 Pa and at the outlet is 0.0205 Pa. Effective area is 5321.4 mm^2 and pressure drop 1744.7 Pa, the pressure distribution is homogenous through the channels, in Figure (3.18 b) the working fluid is H_2 as the pressure at inlet is 758.58 Pa and at the outlet is 0.0035 Pa. Effective area is 5321.4 mm^2 and pressure drop 758.58 Pa. The pressure distribution is homogenous through the channels.

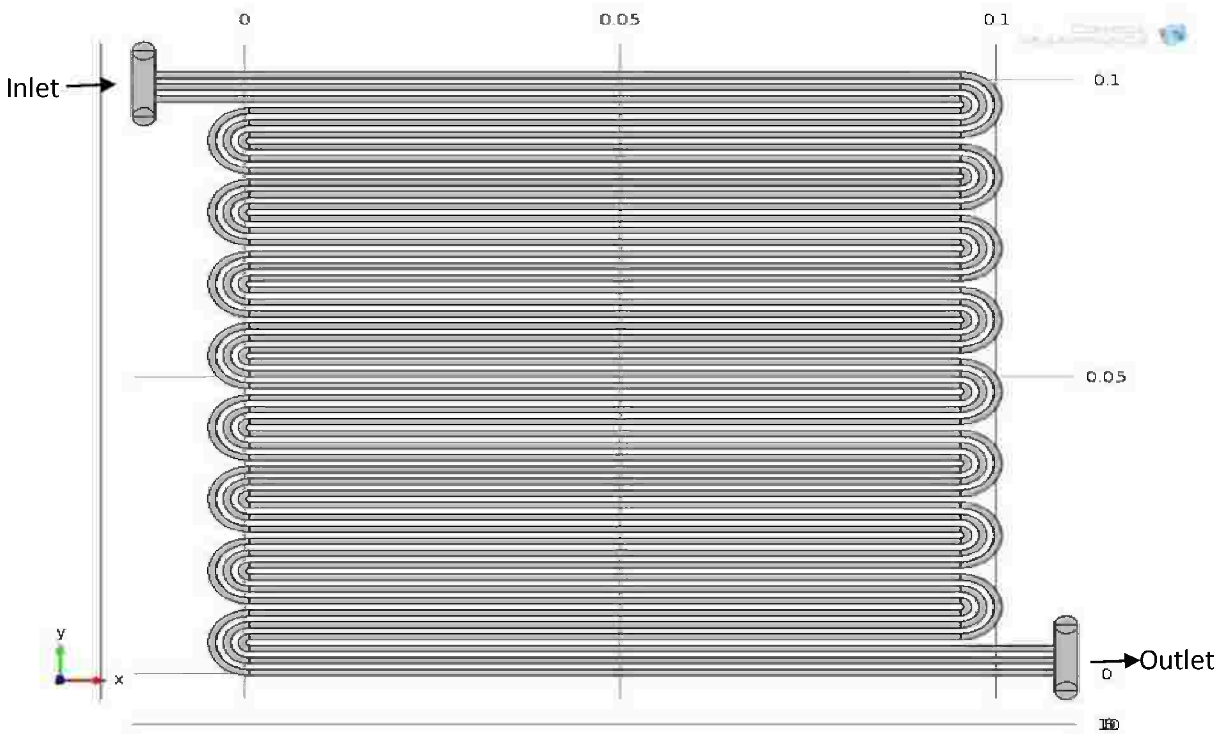
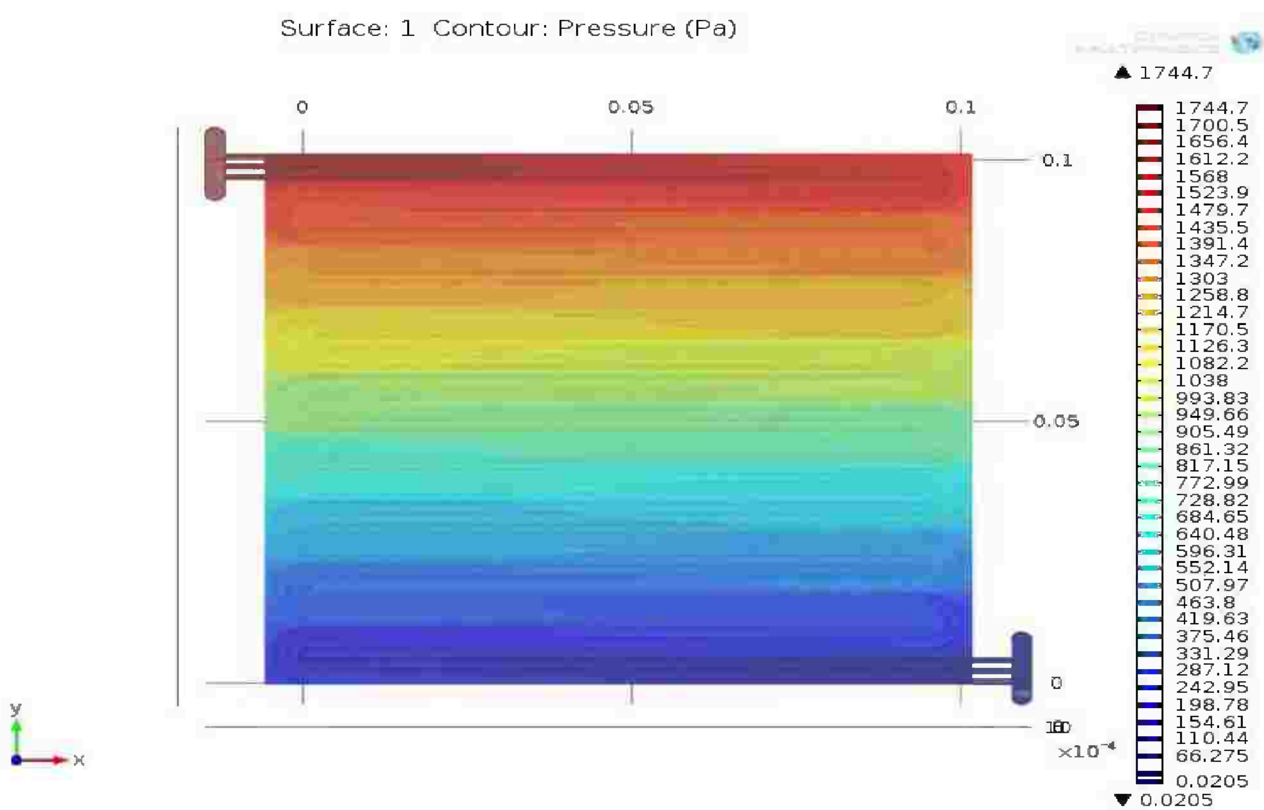
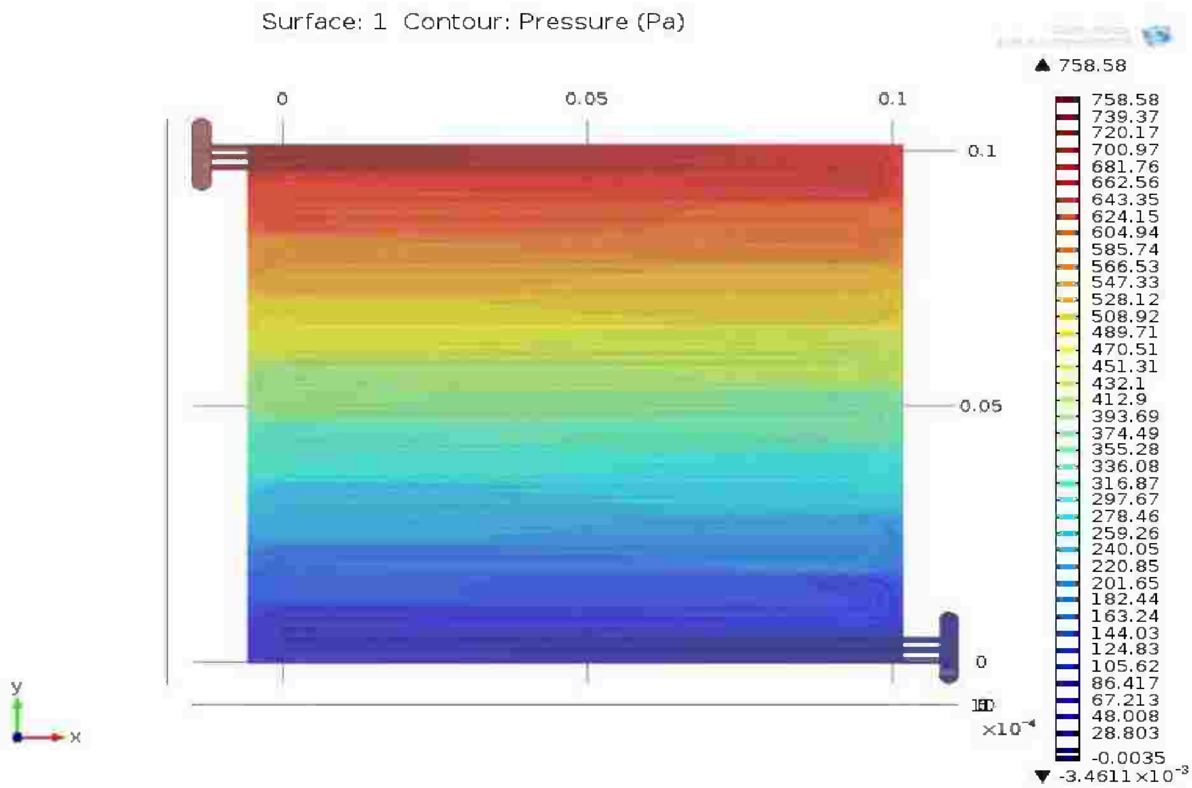


Figure 3.17 2D design for triple serpentine flow channels with curvilinear bend.



(a)



(b)

Figure 3.18 Contour plot for triple serpentine flow channels with curvilinear bend at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.4.3 Six passes serpentine flow channels with curvilinear bend

Figure (3.19) shows two dimension designs for six serpentine flow channels with curvilinear bend with 1 mm width, 1 mm depth and 1 mm rip and number of passes is six and totally number of channels in this design is 54 parallel channels. Figure (3.20) illustrates pressure distribution for sixth serpentine flow channels with curvilinear bends at flow velocity 0.2 m/s. In Figure (3.20 a) the working fluid is air as the pressure at inlet is 430.54 Pa and at the outlet is 0.0827 Pa. Effective area is 5424 mm^2 and pressure drop 430.54 Pa, the pressure distribution is homogenous through the channels, in Figure (3.20 b) the working fluid is H_2 as the pressure at inlet is 203.24 Pa and at the outlet is 0.0205 Pa. Effective area is 5424 mm^2 and pressure drop 203.22 Pa, the pressure distribution is homogenous through the channels.

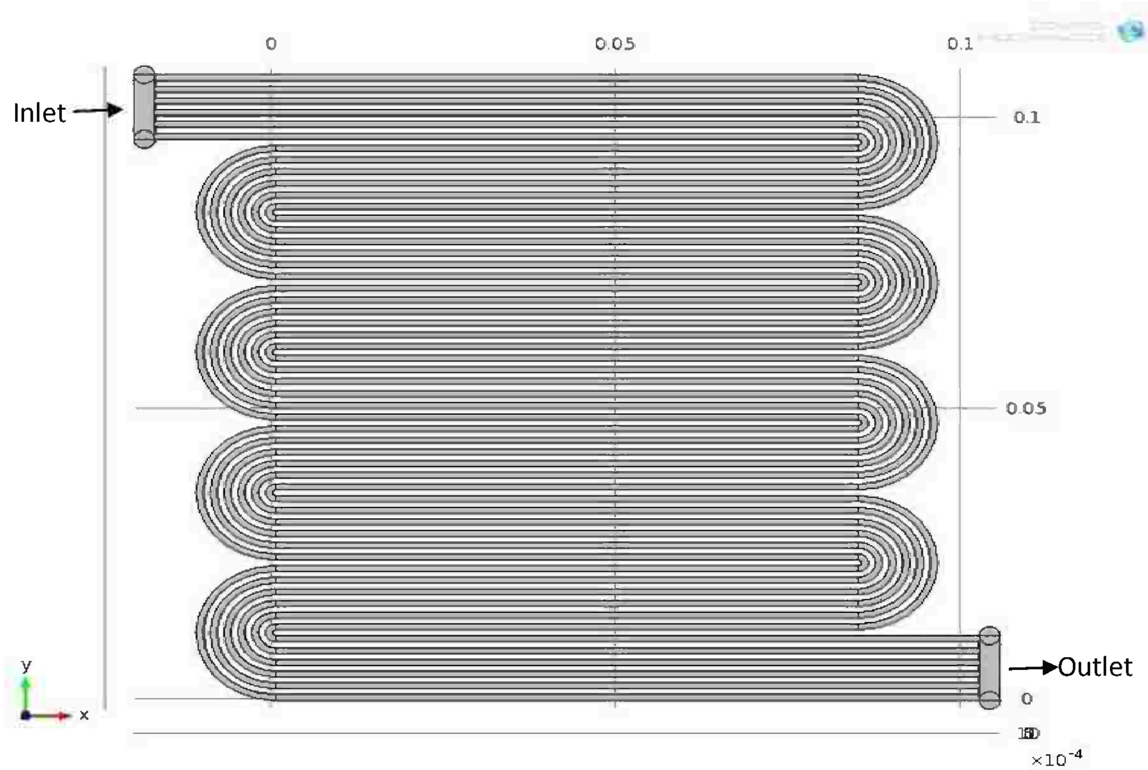
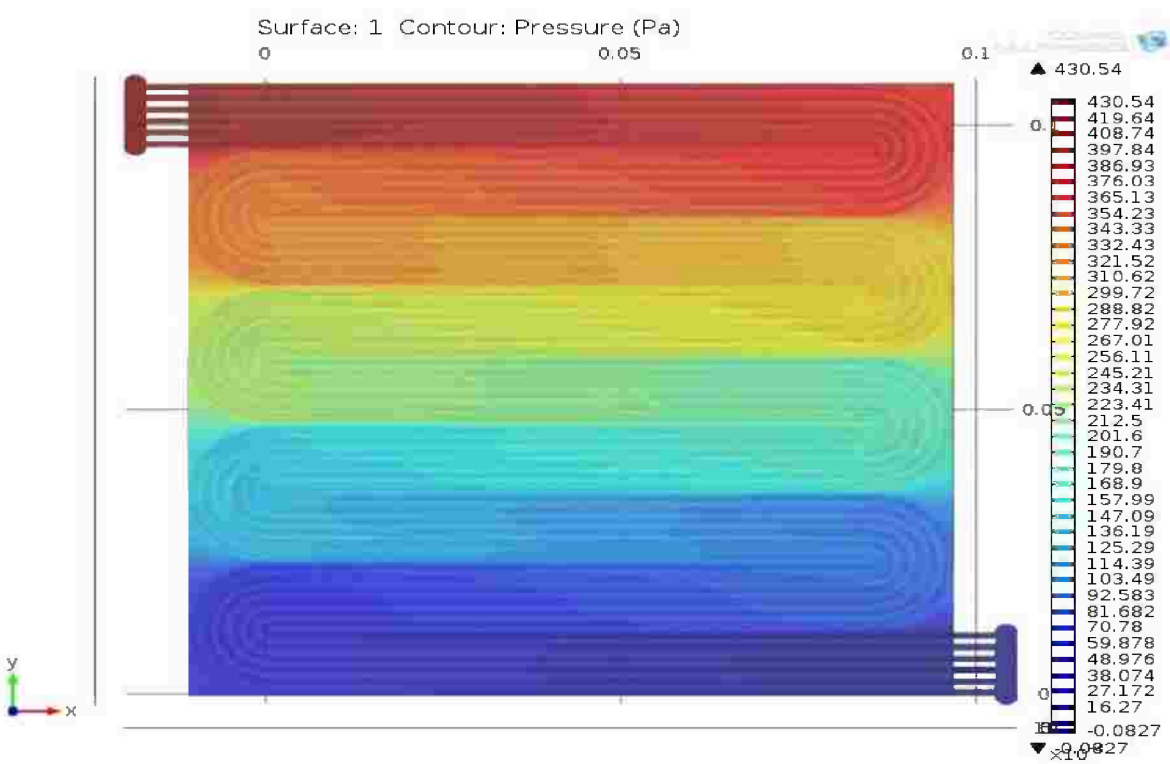
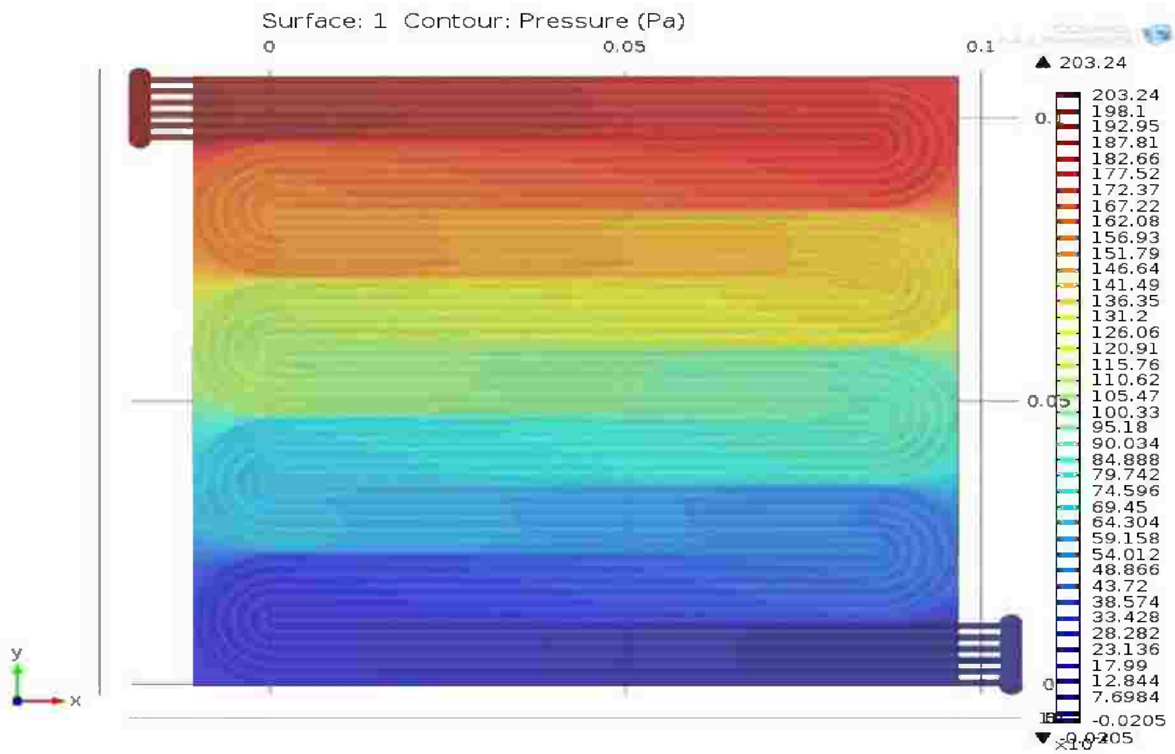


Figure 3.19 2D design for six serpentine flow channels with curvilinear bend.



(a)



(b)

Figure 3.20 Contour plot for six serpentine flow channels with curvilinear bend at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.2.5 Spiral.

Figure (3.21) observes two dimension designs for spiral with 1 mm width, 1 mm depth and 1 mm rip and totally number of turns in this design is 26 parallel channels. Figure (3.22) illustrates pressure distribution for spiral at flow velocity 0.2 m/s. In Figure (3.22 a) the working fluid is air as the pressure at inlet is 115 Pa and at the outlet is 0.41 Pa. Effective area is 4162 mm^2 and pressure drop 114.59 Pa, the pressure distribution is homogenous through the channels, in Figure (3.22 b) the working fluid is H_2 as the pressure at inlet is 55.6 Pa and at the outlet is 0.2 Pa. Effective area is 4162 mm^2 and pressure drop 55.4 Pa, the pressure distribution is homogenous through the channels.

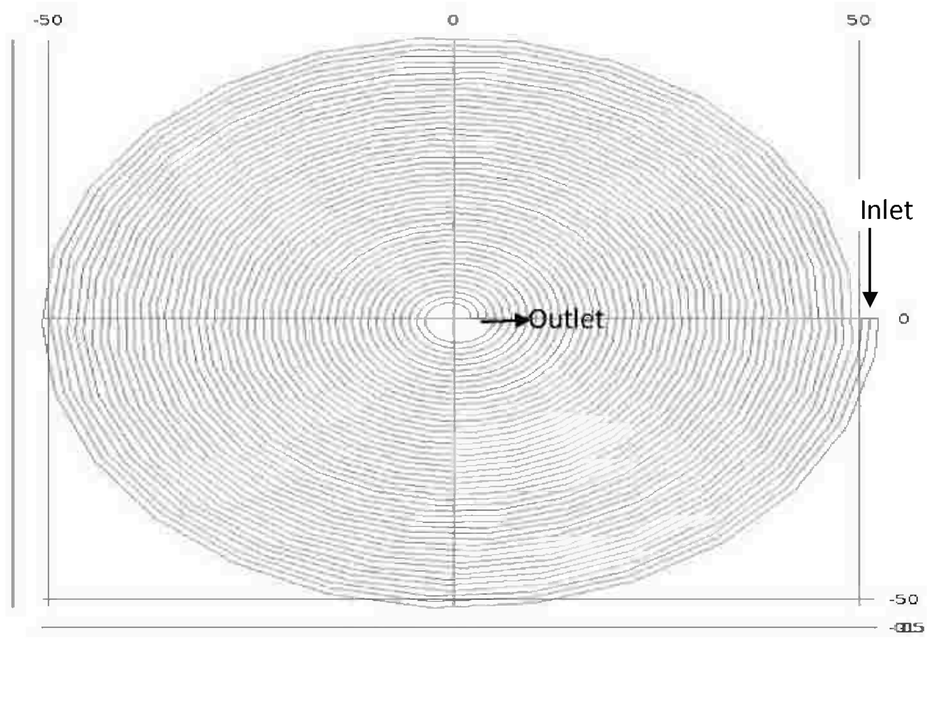
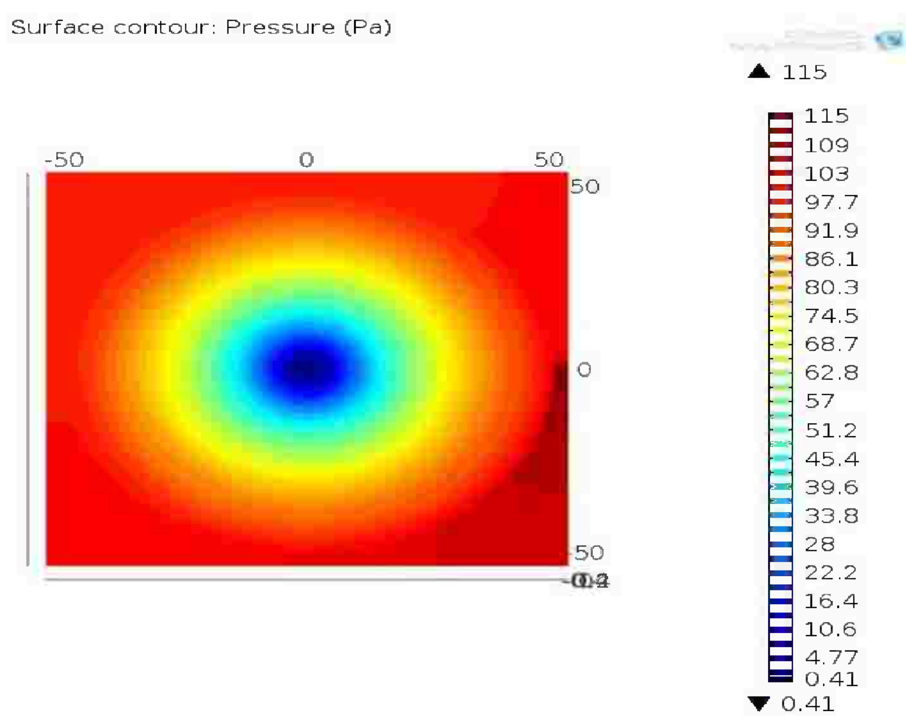
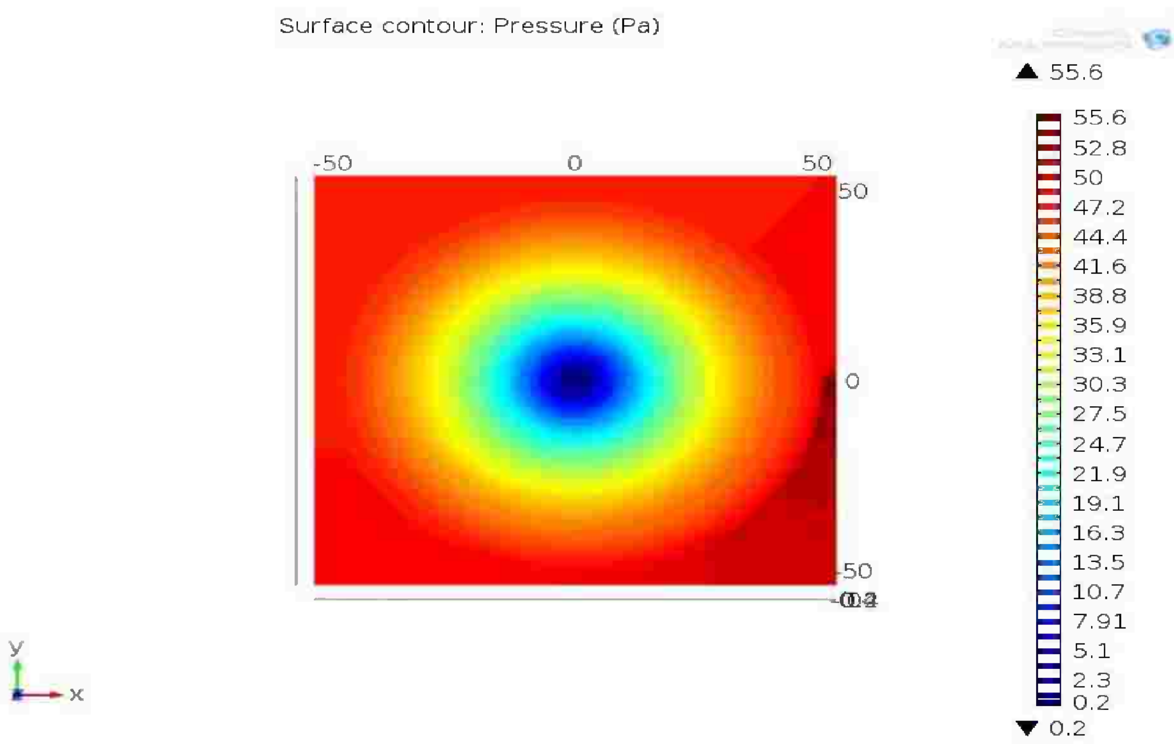


Figure 3.21 2D design for spiral.



(a)



(b)

Figure 3.22 Contour plot for Spiral design at flow velocity 0.2 m/s (a) For air, (b) For H_2.

3.3 SUMMARY OF NUMERICAL RESULTS

In this study the main effective parameters were pressure drop, effective area and residence time .pressure drop must be minimize to minimize the consumed power for compressor.

Figure 3.23 shows pressure drop for channels header serpentine designs (dual, triple and six) for both air and hydrogen. The results demonstrated the six channels header serpentine achieved the minimum pressure drop for both air and hydrogen gases. The air pressure drop through the six channels header serpentine is 1142.7 Pa while at triple channels header serpentine is 2186.7 Pa and pressure drop at dual channels header serpentine is 3860.2 Pa. The same trend was obtained when hydrogen was used where the six channels header serpentine achieved 387.75 Pa compared by triple channels header serpentine had 876.3 Pa and dual channels header serpentine had 1646.8 Pa.

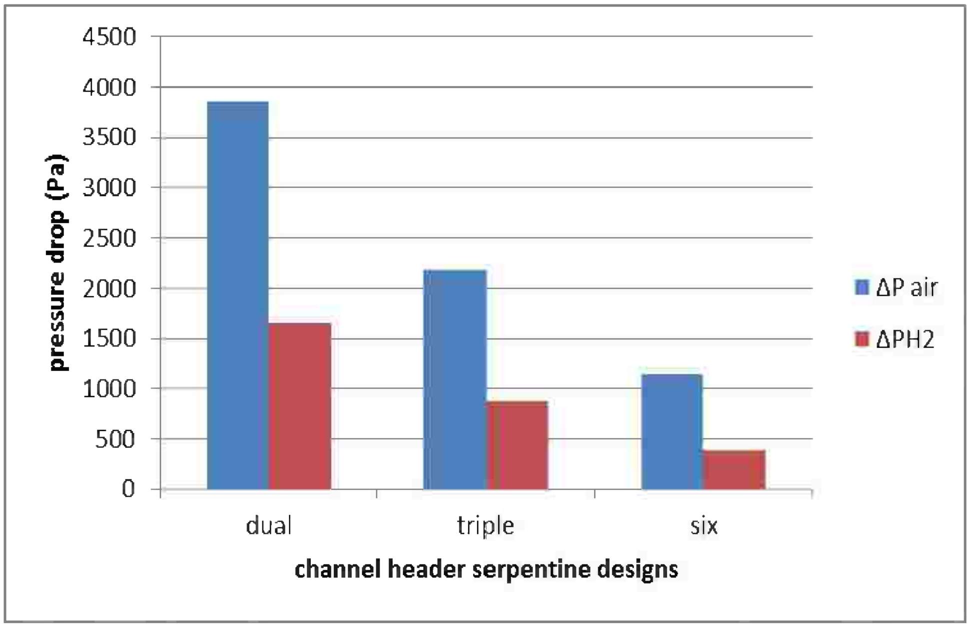


Figure 3.23 Relations between pressure drop for channels header serpentine designs for air and hydrogen (for constant bipolar plate area).

The same trend was notice for channels with square bends designs and for channels with curvilinear bends designs the graphical results and numerical figures are shown in figure 3.24 and 3.25 and table 3.1.

The reason for the results in figure 3.23, 3.24 and 3.25 is attributed the six channels in each type has the gas path length shorter than dual and triple channels.

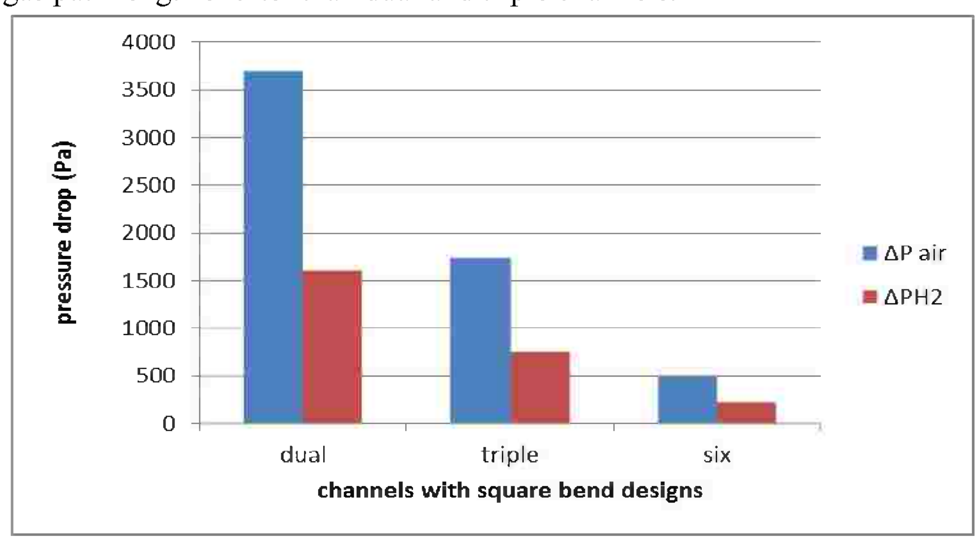


Figure 3.24 Relations between pressure drop for channels with square bend designs for air and hydrogen (for constant bipolar plate area).

Table 3.1 Results summarized for different types of bipolar plates for air and H_2 at 0.2 m/s.

NO.	Design	ΔP_{air} (Pa)	ΔP_{H_2} (Pa)	Effective area (mm^2)	Time (s)
1	Parallel or straight bipolar plate	10.7	5.17	5671	0.535
2	Dual channel header serpentine.	3860.2	1646.8	5880	29.4
3	Triple channel header serpentine.	2186.7	876.3	5573	27.865
4	Six channel header serpentine.	1142.7	387.75	5938	29.69
5	Dual serpentine flow channels with square bends.	3695.1	1599	5854	29.27
6	Triple serpentine flow channels with square bends.	1737.6	758.55	5541	27.7
7	Six serpentine flow channels with square bends.	487.66	221.78	5898	29.5
8	Dual serpentine flow channels with curvilinear bends.	1865.1	897.24	5714.7	28.57
9	Triple serpentine flow channels with curvilinear bends.	1774.7	758.58	5321.4	26.6
10	Six serpentine flow channels with curvilinear bends.	430.54	203.22	5424	27.1
11	Spiral design	114.59	55.4	4162	20.8

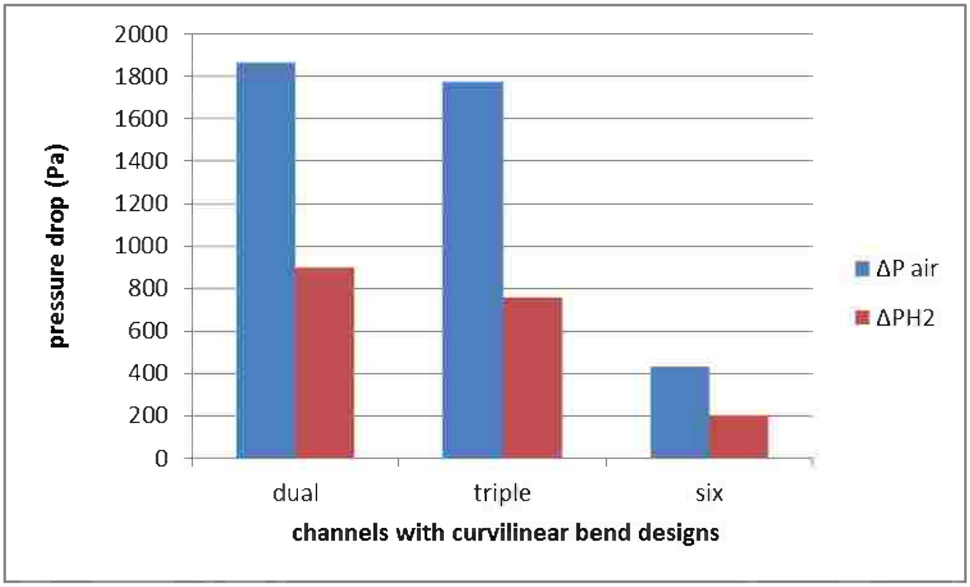


Figure 3.25 Relations between pressure drop for channels with curvilinear bend designs for air and hydrogen (for constant bipolar plate area).

A compression of the six channels designs for different configuration indicates that the six channels with curvilinear bend design achieved the minimum pressure drop 430.54 Pa for air and 203.22 Pa for hydrogen is shown in figure 3.26.This is due to absence of sharp turns in the curvilinear bends design and consequently the gases flow with no eddies or vortices.

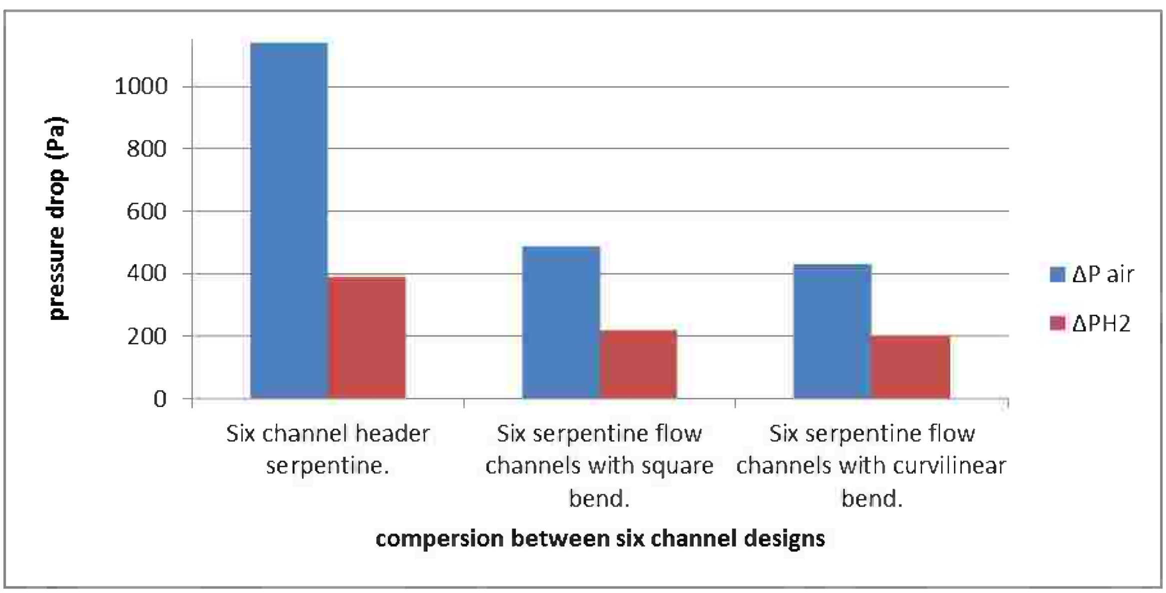


Figure 3.26 Relations between pressure drop for six channels designs for air and hydrogen (for constant bipolar plate area).

Lastly, a compression between the six channels with curvilinear bend design, parallel or straight bipolar plate and spiral design for air and hydrogen is (shown in figure 3.27) indicates that for both air and hydrogen parallel or straight bipolar plate achieved the minimum pressure drop.

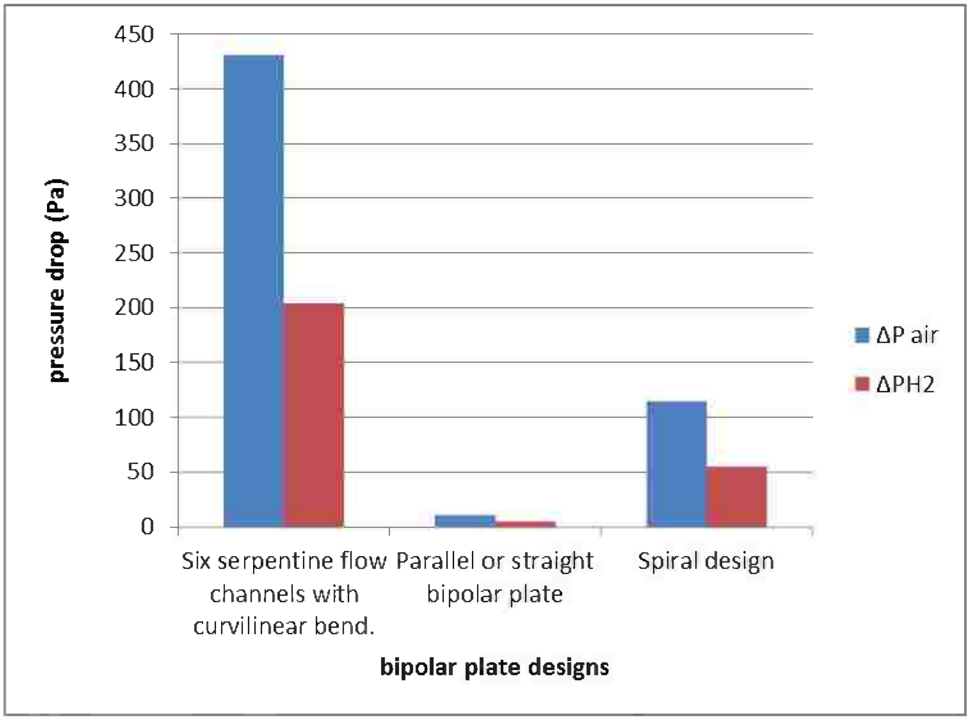


Figure 3.27 Relations between pressure drop for other designs for air and hydrogen (for constant bipolar plate area).

The second important parameter is effective area which must maximize to maximize the recation surface consequently the performance of fuel cell.

Figure 3.28 illustrates the effective area for the eleven selected bipolar plate designs. The six channels header serpentine showed the maximum effective area.

The last important parameter is residence time which must be suitable for all amounts of gases to react.

Figure 3.29 illustrates residence time for the eleven selected bipolar plate designs. All designs have suitable residence time except parallel or straight bipolar plate design.

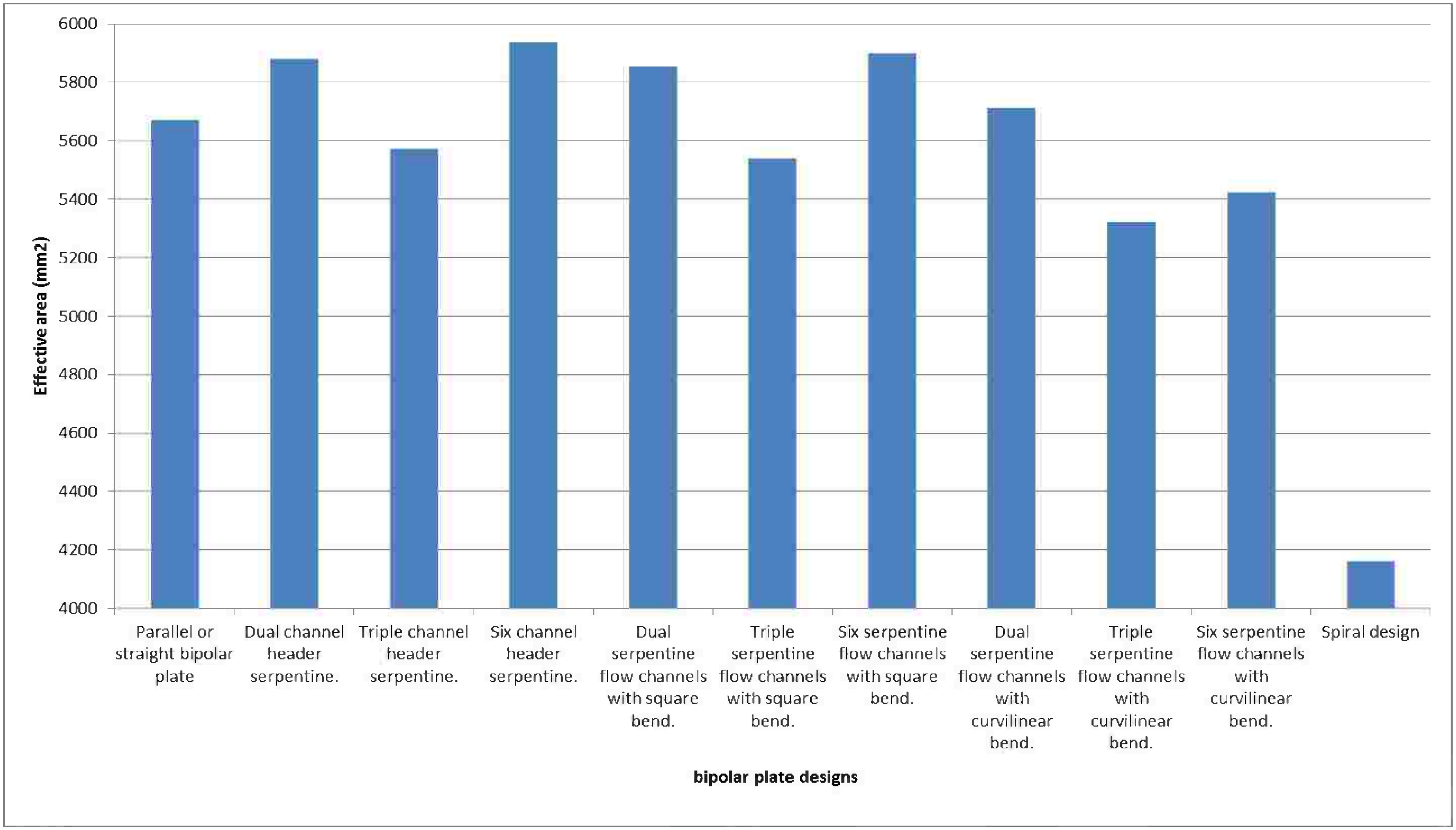


Figure 3.28 The effective areas for bipolar plate designs

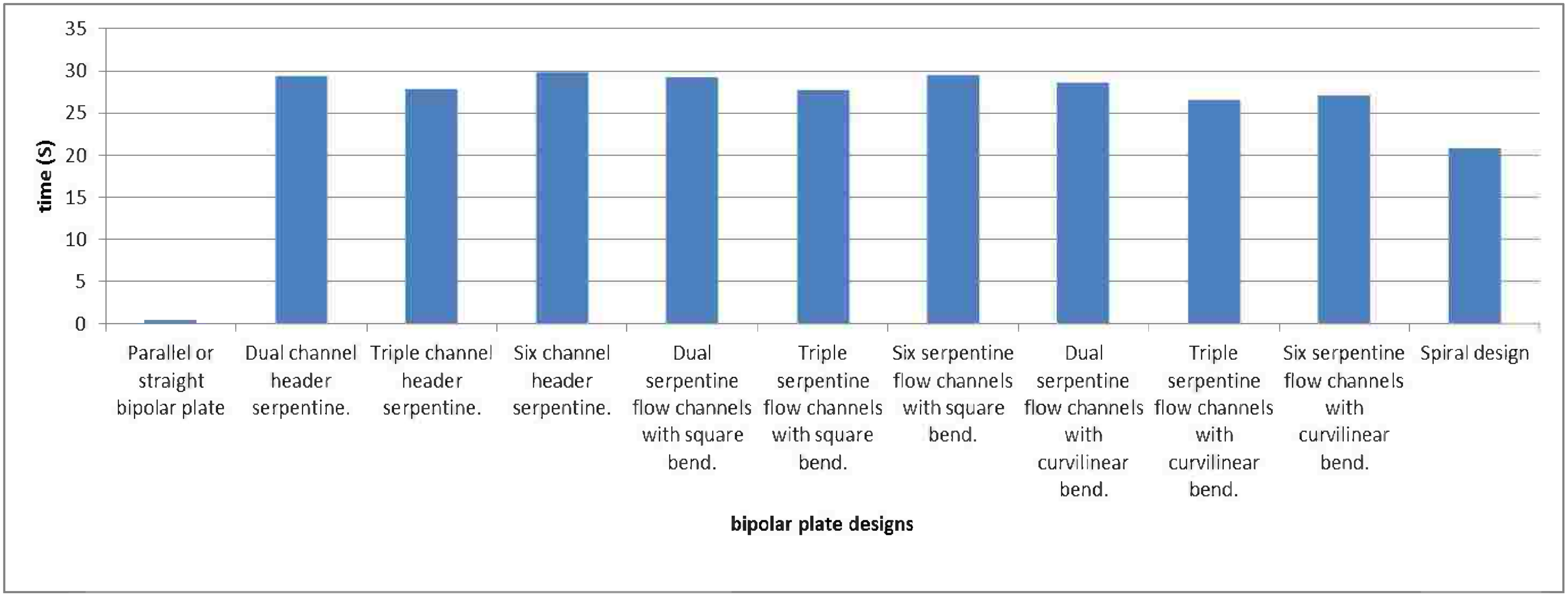


Figure 3.29 The residence times for bipolar plate designs

3.4 PARAMETRIC STUDY

This chapter a parametric study has been carried out to study the different parameters effects on bipolar plates performance consequently the PEMFC performance to get the optimal design of the bipolar plate in the PEMFC system. The parametric study has performed numerically by using the mathematical model mentioned in chapter 2 using COMSOL 4.2 software is a CFD model. The parameters studied are: different gas (air or H_2) velocities, bipolar plate channel width, bipolar plate channel depth and bipolar plate channel cross sections shape as triangle, semicircle, trapezoidal and square.

3.4.1 Effect of gas (air or H_2) velocity.

Different velocities have been applied for both side's air (cathode side) and H_2 (anode side) and their values were 0.02 m/s, 0.04 m/s, 0.06 m/s, 0.08 m/s, 0.1 m/s,0.12 m/s, 0.14 m/s, 0.16 m/s, 0.18 m/s and 0.2 m/s.

Pressure drop has been increased with velocity increased in both side's air (cathode side) and H_2 (anode side) as shown in figure (3.30).

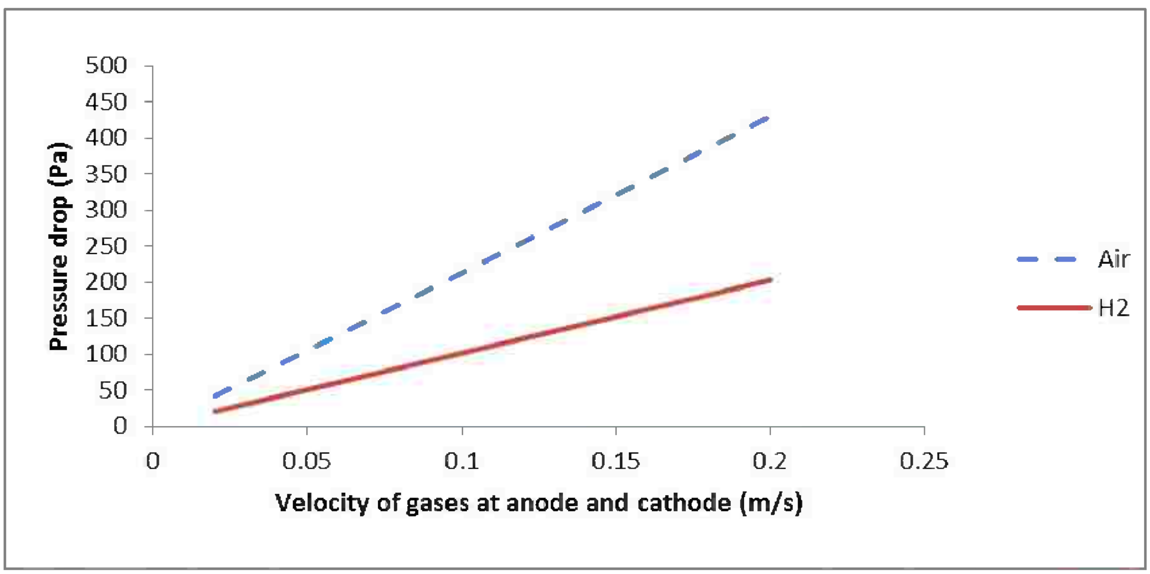


Figure 3.30 Comparison between different gas (air or H_2) velocity.

3.4.2 Bipolar plate channel width

Different channel widths have been applied for both side's air (cathode side) and H_2 (anode side) and their values were 1 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, 1.8 mm, 1.9 mm and 2 mm in order to investigate their effect on the pressure drop.

Pressure drop has been decreased with increasing channel width in both side's air (cathode side) and H_2 (anode side) as shown in figure (3.31).

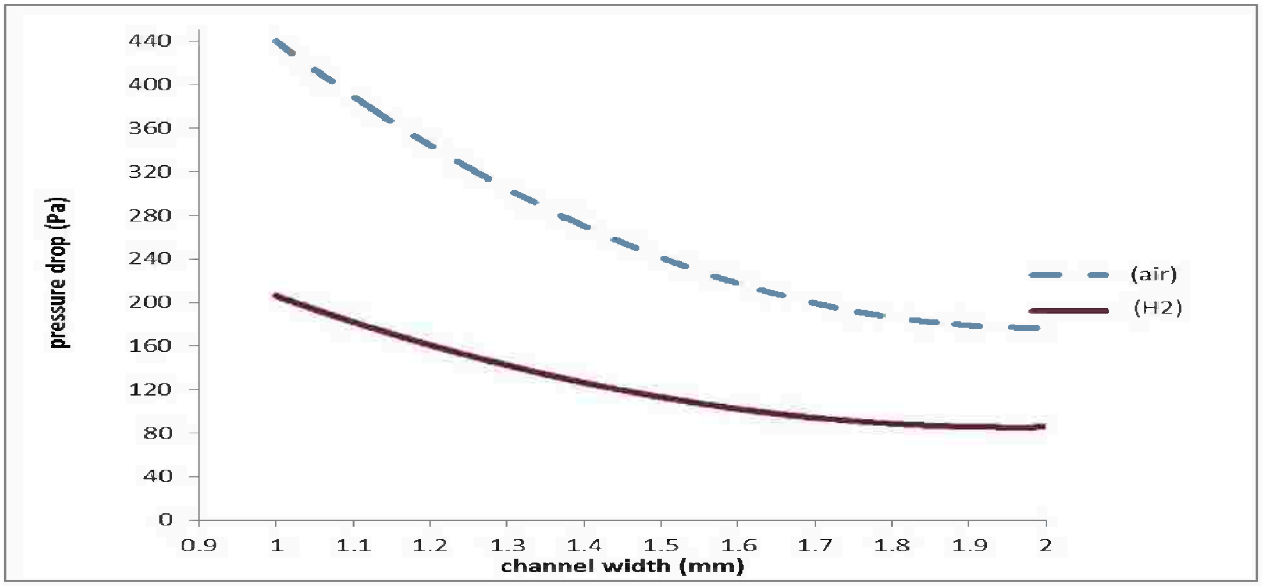


Figure 3.31 Variation of pressure drop with channel width for both gases used.

3.4.3 Bipolar plate channel depth

Different channel depths have been applied for both side's air (cathode side) and H_2 (anode side) and their values were 0.5 mm, 1 mm, 1.5 mm, 2 mm and 2.5 mm in order to investigate their effect on the pressure drop.

Pressure drop has been decreased with increasing channel width in both side's air (cathode side) and H_2 (anode side) as shown in figure (3.32).

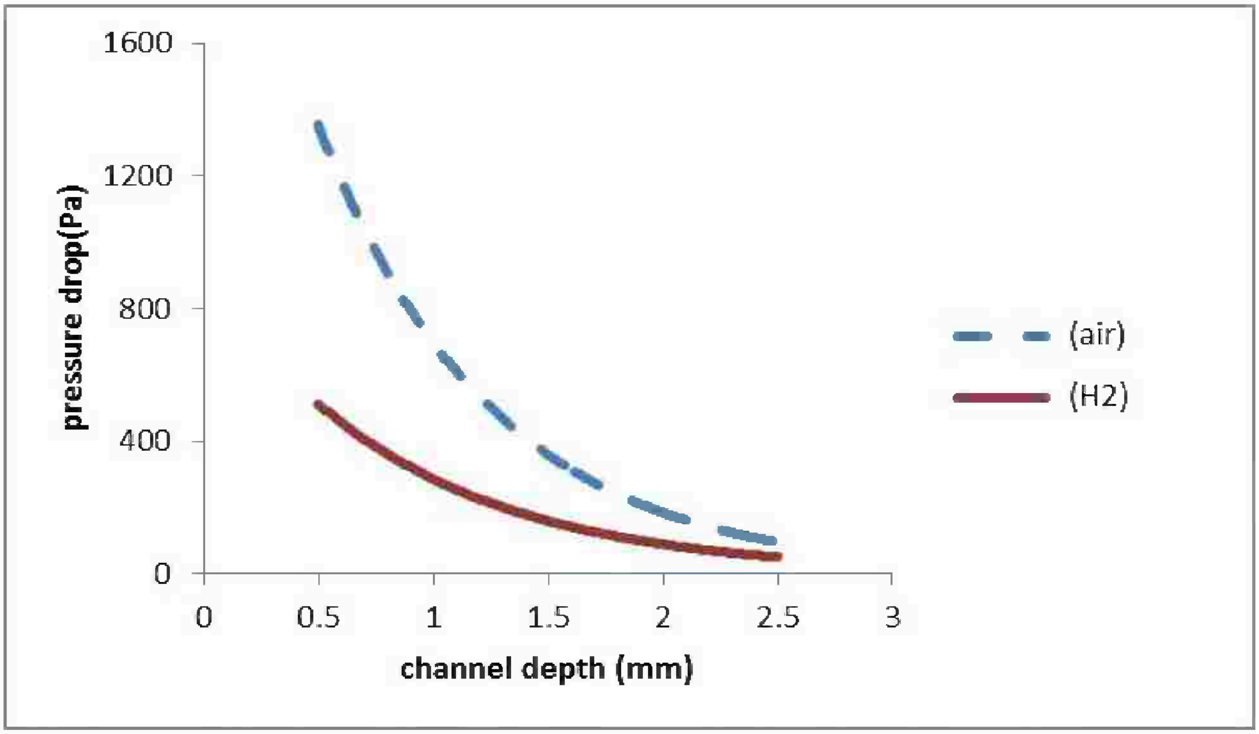


Figure 3.32 Variation of pressure drop with channel depth for both gases used.

3.4.4 Bipolar plate channel cross sections

3.4.4.1 Different cross sections shape at different air velocities.

Different channel cross sections designs have been studied with different velocities for air side (cathode side). These cross sections are square, semicircle, trapezoidal and triangle. For each design different velocities were 0.02 m/s, 0.006 m/s, 0.1 m/s, 0.14 m/s, 0.18 m/s and 0.2 m/s were applied.

For each design pressure drop increases with the increase of air velocities. But for each velocity the lowest pressure drop occurs at semicircle design followed by square design then trapezoidal design finally triangle design as shown in figure (3.33).

So the optimum cross section design is semicircle design followed by square design in air side (cathode side) as shown in figure (3.33).

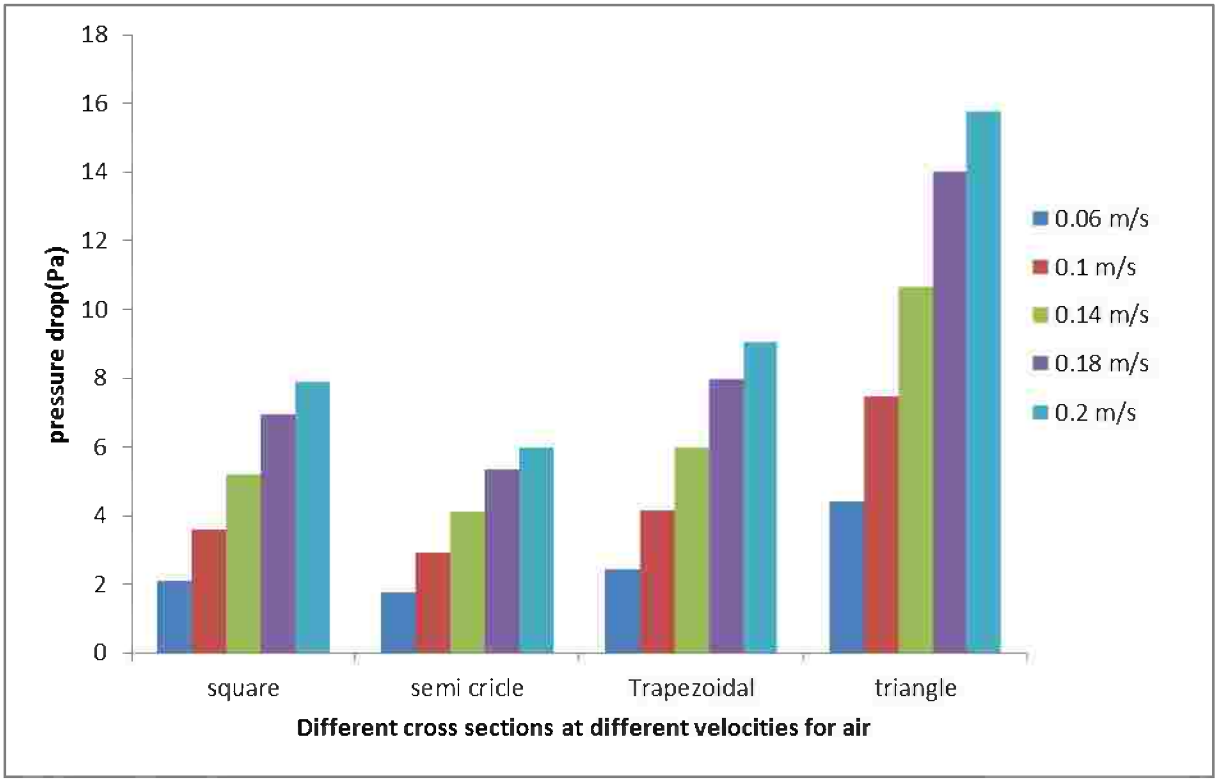


Figure 3.33 Relations between different channel cross sections and pressure drop at different velocities for air (for constant cross section area).

3.4.4.2 Different cross sections shape at different H_2 velocities

In this investigation different channel cross sections designs have been studied with different velocities for H_2 side (anode side). These cross sections are square, semicircle, trapezoidal and triangle. For each design different velocities were 0.02 m/s, 0.006 m/s, 0.1 m/s, 0.14 m/s, 0.18 m/s and 0.2 m/s are used.

For each design pressure drop increases with the increase of H_2 velocities. But for each velocity the lowest pressure drop is semicircle design followed by square design then trapezoidal design finally triangle design as shown in figure (3.34).

So the optimum cross section design is semicircle design followed by square design in H_2 side (anode side) as shown in figure (3.34).