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Flow Visualization Studies through Disc and Donut Baffles

B.H.L. Gowda, B. K. Srinivas, P. N. Bhushan, D. Dhananjeya Shetty,
J. C. Kishore and H. Manoj Kumar
Department of Mechanical Engineering,
BTL Institute of Technology, Bangalore-560099

***Abstract* - An experimental study has been carried out to investigate the detailed flow field inside an open channel containing 2,3,4,5 and 6 sets of disc and donut baffles. During the experiment different parameters are varied such as the ratio of width of disc to the width of the donut aperture (d/D) for (1,1.2,1.4 & 1.6) and also the ratio of pitch to the width of channel (p/B) for (0.3,0.4 & 0.5) is varied. This is an important criteria of heat transfer in nuclear industries, chemical industrial processes, drying processes etc. The obtained results indicate that the number of baffle plates, baffle plate length have significant effect on flow field giving rise to the possibility of varying turbulent intensity and the retention time in different situations. The largest variation of flow field occurs near the tips of the baffles. The result reveals the nature of complex flow field due to interference effects.**

Keywords: Baffles, Channel, Disc and Donut type baffles.

INTRODUCTION

Baffle plates are very commonly used in heat exchangers, nuclear power plant, turbine blades, solar collectors and electronic components. The baffles act as passive elements to enhance the heat transfer between hot and cold fluids. In shell-and–tube heat exchangers, the baffle plates are responsible for changing the direction of flow and for increasing the heat exchange time between fluid and the heating surface. Understanding of flows through baffles is important due to their relevance to many practical problems as mentioned above. Disc and donut baffles are used commonly to reprocess spent nuclear fuels.

Taborek et al [1] used the disc and donut on the shell side only expecting energy saving. Their study shows that the pressure drop may be modified by both the baffle spacing and the baffle edge overlap. They infer that the discand donut baffles can be used for a variety of services as alternatives to both segmental and double segmental baffles. Li and Kottke [2] made heat transfer studies in two representative baffle compartments of a shell-and-tube heat exchanger with disc and donut baffles. They found that the disc and donut baffles have a higher effectiveness of heat transfer to pressure drop than single segmental baffles. Angelov and Gourdon [3] investigated numerically, using k-ε model, the turbulent energy parameters of single phase pulsed flow in an extraction column with internals of immobile disc and donuts. Torab-Mostaedi et al [4] carried out an experimental study of the dispersed phase hold up of a pulsed disc and donut extraction column. The results show that the hold up is drastically affected by the pulsation intensity and interfacial tension. Lobry et al [5] used the disc and donut pulsed column co-currently to create a liquid-liquid dispersion. A surfactant as been used and different parameters have been investigated and their effect on the mean droplet size has been studied. Rajnish Kumar et al studied the hydrodynamic parameters, namely, dispersed phase hold up and flooding throughout, in a 25 mm diameter pulsed disc and donut column in no mass transfer condition. A good agreement has been obtained between experimental values and predicted values obtained from empirical correlations.

The objective of the present work is to understand the flow field around a series of disc and donut baffles arranged in a channel using flow visualization. The configuration considered is shown in Fig.1. In this figure, L is the length of the channel, B, the width, P is the pitch, D is the width of the donut aperture, d is the width of the disc, and a is the width of the donut. The results are obtained for varying number of disc and donut baffles with different relative sizes of disc and donut.

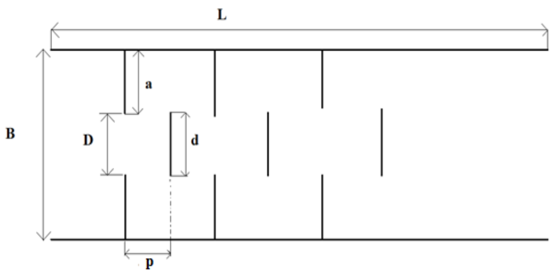

Fig.1: Configuration considered

EXPERIMENTAL ARRANGEMENT

Experiments have been conducted using Flow Visualization Facility which is available at the fluid mechanics laboratory, Department of Mechanical Engineering, B.T.L.Institute of Technology. This facility consists of a F.R.P tank with 2.5m length and breadth of 1.5m (Fig.2) and a set of aluminum discs, separated by a small distance are located at one end of the tank. The discs are connected to a three phase induction motor with cooling arrangement through a set of bevel gears and the flow created from the rotation of the discs is guided into the test section by two guide blocks made of FRP. The width of this test section is 350 mm. By controlling the speed of the motor, the speed in test section could be varied continuously up to 0.2 m/s. At higher speeds the water becomes wavy and hence for the experiments a suitable speed is chosen where such waves do not occur.

Three cases are considered with p/B = 0.3,0.4 and 0.5 keeping width of the channel constant (150mm) as shown in figure and provision for fixing different number of sets of donut-disc baffles was made out of MS plates of 2mm thickness. The ratio of width of disc to the length of donut aperture (d/D) and number of sets of donut-disc baffle plates can be varied. For the first case (p/B=0.3) the number of sets of baffles plates, n=2, 3,4,5,6 are used in an open channel. For the second case (p/B=0.4) the number of sets of baffles plates, n=2, 3,4,5,6 are used. For the third case (p/B=0.5) the number of sets of baffles plates, n=2, 3,4,5,6 are used in an open channel. For each case, experiments are conducted with different sizes of disc plates, d=75, 90,105 and 120mm. The corresponding values of d/D are 1, 1.2, 1.4, and 1.6. Considerable care was taken to arrange these baffle plates in the slots provided on the sides in such a way that they were placed according to the different spacing.

In the preliminary studies carried out, experiments were at free stream velocity of 0.15 m/s (aluminum disc rotation = 30 rpm), 0.19 m/s (aluminum disc rotation = 35 rpm) and 0.21 m/s (aluminum disc rotation = 40 rpm). At low free stream velocity no flow was passing through the baffle plates and at higher stream velocity the water surface became wavy. Hence to overcome these problems all the results are obtained at free stream velocity of 0.19 m/s which corresponds to a Reynolds number of 6000. Fine aluminum powder is used as a tracer medium, Single-Lens Reflex (SLR) camera is used to photograph the flow field. The camera will be placed at a suitable height above the channel containing baffle plates. Two Halogen 500 watts lamps are used to obtain proper lighting.

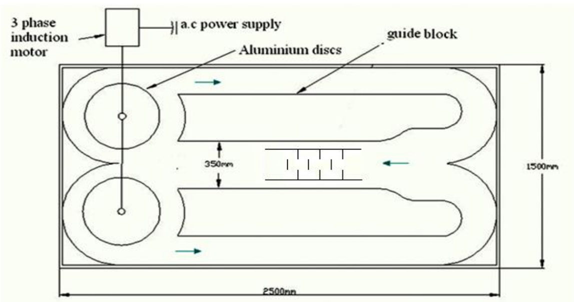

Fig.2: Experimental arrangement

RESULTS

As mentioned earlier, results have been obtained for p/B = 0.3, 0.4 and 0.5. For each value of p/B, results for n = 2, 3 4, 5 and 6 have been obtained. However, only results for n = 2, 4 and 6 are presented below.

Case 1: Results for p/B = 0.3

The results with p/B = 0.3 and n = 2 for values of d/D = 1.0, 1.2, 1.4 and 1.6 are shown in Fig. 3a to d. As can be seen as d/D increases the relative length of the disc increases. In Fig.3a (d/D = 1), as the flow enters the donut a stagnation zone is formed on the front side of the disc, followed by the separation of flow at the two edges of the disc. Due to this, tip vortices are seen and the flow goes round these and exit through the second donut. Recirculation regions are formed at the edges of the second donut. These recirculation regions become larger and intensify as d/D increases (Fig.3b to d). Further the flow exiting from the second donut gives rise to a sharp stagnation zone on the front side of the second disc. The flow moves along the face of the second disc and separate at the edges. As a result a large wake is formed behind the second disc. The pattern of this wake region changes with change in d/D value (Fig.3a to d). There is stronger flow along the wall at exit as d/D increases.

Results for n = 4 are given in Fig.4a to d. Here as the number of plates have increased, the flow has to pass through a longer path. Also the path is circuitous with a number of twists and turns. As the recirculation regions have increased, an increase in losses can be expected. The near wall flow and the size of the wake behind the last disc changes as the d/D value increases (Fig.4a to d). For n = 6 (Fig.5a to d), the path as become still longer resulting in reduced energy of the flow towards the exit end i.e., the last disc. An increased pressure drop can be expected along the channel after each set of donut and disc. The retention time increases as the number of donut and disc increase.

Case2: Results for p/B = 0.4

The results for n=2 with p/B = 0.4 are shown in Fig.6a to d. Here the distance between the donut and the disc has increased compared to the case with p/B = 0.3. This increase appears to cause considerable influence on the flow field at all values of d/D compared to that for p/B = 0.3. At d/D = 1 (Fig.6a), the increased distance between the donut and the disc has made the flow through the donut stronger with two recirculation regions behind the donut. The flow separating from the disc is strongly biased upwards forming a large wake just behind the disc enclosing two vortical regions. The flow exiting from the second donut is influenced by this and a strong impinging flow on the second disc is seen. The flow along the surface of the disc separates at the edges of the disc and a wall-jet like flow occurs along the channel sides. A large wake with vortices are formed behind the disc. As d/D increases (Fig.6b to d), the flow field is similar to what is given above. However, three changes are seen: 1) the size of the two vortices behind the first donut decreases due to the increased bias in the turning flow, 2) the vortical pattern between the second donut and the disc change with more number of vortices and 3) the wall-jet like flow issuing from the tips of the second donut becomes stronger and extends to a large distance downstream.

For n = 4, due to the increased number of donut and disc, for d/D = 1 (Fig.7a) four vortical patterns are seen behind the disc. Behind discs 2 and 3, these patterns seems to have merged into two. There is almost a dead water region behind the last disc bounded by jet –like flow at the channel walls. As d/D increases (Fig.7b to d), the vortical pattern behind the discs change due to the increased upward bias at the edges of the discs. Also the impinging flow on successive discs narrow due to the same reason and the flow along the front face of the successive discs intensify. The wall-jet like flow exists at the last disc and the wake behind which is nearly a dead water region. For n = 6 Fig.8a to d), due to the increased number of donuts and discs, the fluid path as increased considerably resulting in increases losses. This becomes evident in the weak vortical patterns along the flow and also the weak exit flow at the two ends of the last disc. This leads to a set of vortices behind the last disc (Fig.8c and d).

Case3: Results for p/B = 0.5

The results for this value of p/B for n = 2, 4 and 6 are respectively shown in Figs. 9, 10 and 11. For n=2 (Fig.9a to d), due to the increased distance between the donut and the disc, the impinging flow and the flow along the faces of the discs have become stronger. Stronger turning flow and vortices are seen behind the donuts. Further the jet-like exit flow at the two ends of the last disc is strong at all values of d/D. Several vortical patterns are seen behind the last disc.

For n=4 (Fig.10a to d), due to the increased path of the flow and the increased obstruction, losses increase and the energy of the flow decreases. Except for the case of d/D=1 (Fig.9a), this becomes evident in the weak vortical patterns seen. The wake behind the last disc at all values of d/D is nearly a dead water region. For n=6 (Fig.11a to d), the pattern seen for n=4, continues. However, the flow field in front and behind the last disc is different. The increased circuitous path of the flow leads to increased losses and the exit jet like flow from the last disc does not extend too far into the wake. It is entrained in to the near wake giving rise to vortical patterns.

CONCLUDING REMARKS

Flow visualization results have been presented for donut disc baffles with different distance between the two (p/B ratio). The number of baffles (n) are varied and for each n, results are obtained for various ratios of donut opening and the disc size (d/D).

The results show that each of the parameter influences the flow field. When the pitch increases the impinging flow on the discs intensify on the front side and a strong flow along the disc occurs. When n is increased, the path of the flow increases and also the path becomes circuitous. This can have significant effect on the retention time, turbulence and heat transfer rates. At any given value of p/B and n, the value of d/D influences the vortical pattern between the donut and the disc. Also the exit flow at the end disc vary depending on d/D ratio. The study presented can act as a guide to suitably choose the number of donut and disc and their positioning in practical applications.

ACKNOWLEDGEMENTS

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NOMENCLATURE

L Length of the channel
B Width of the channel
D Width of the donut aperture
a Width of the donut
d Width of the disc

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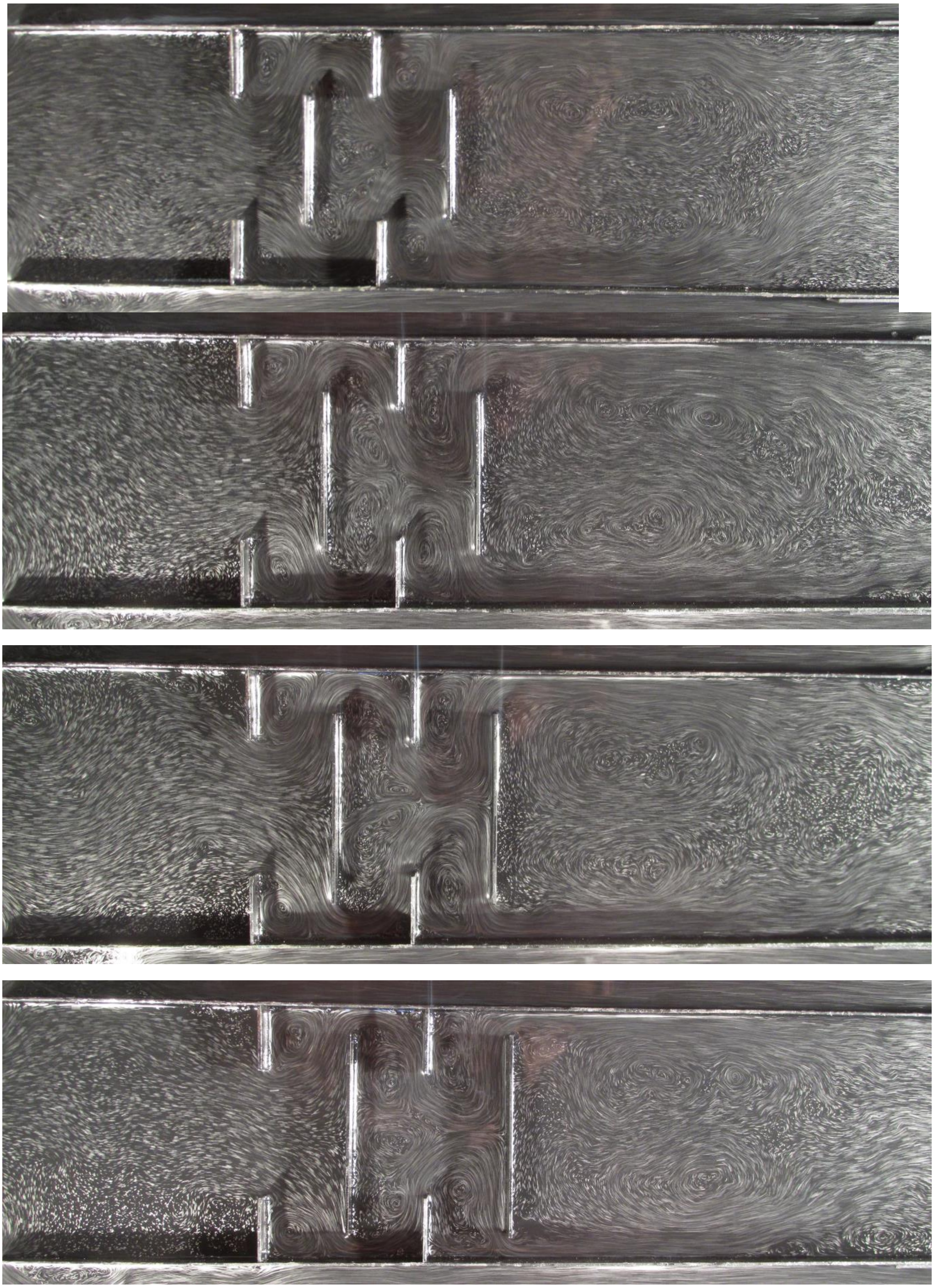

d/D
(a) 1.0
(b) 1.2
(c) 1.4
(d) =1.6

Fig.3 : Flow patterns for n=2, p/B=0.3

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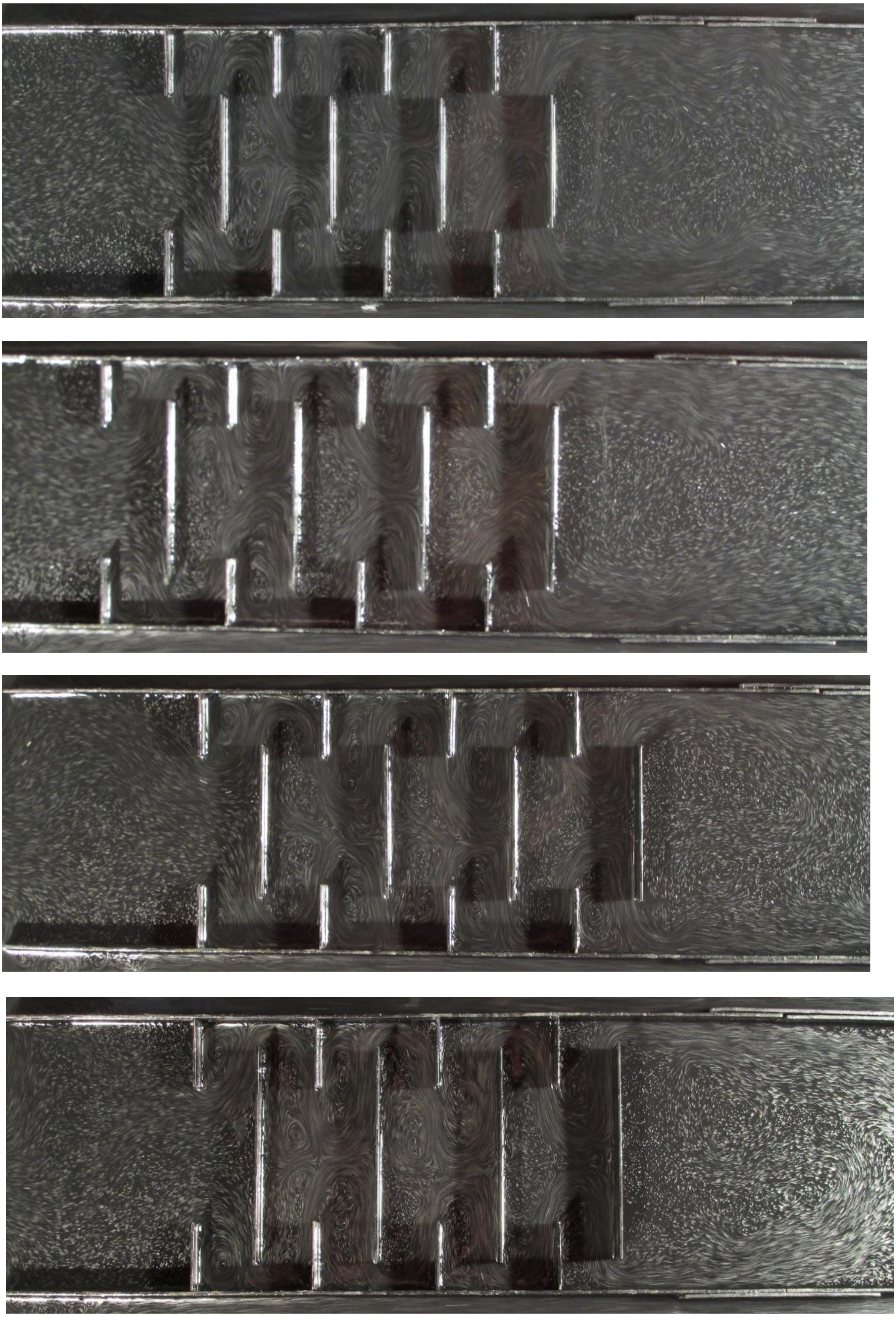

d/D

(a) 1.0

(b) 1.2

(c) 1.4

(d) 1.6

Fig 4: flow patterns for n=4, p/B=0.3

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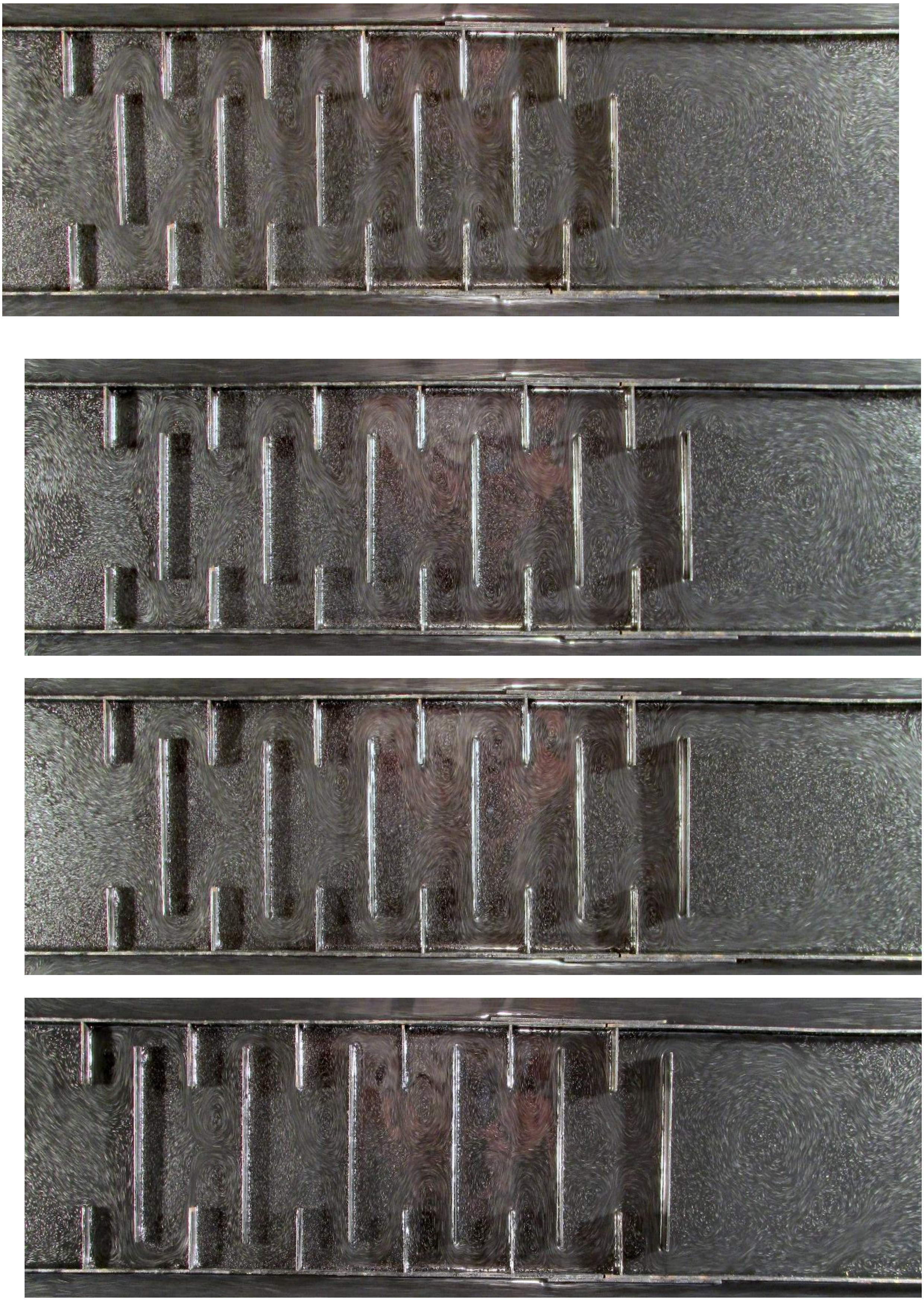

d/D

(a) 1.0

(b) 1.2

(c) 1.4

(d) 1.6

Fig 5: flow patterns for n=6, p/B=0.3

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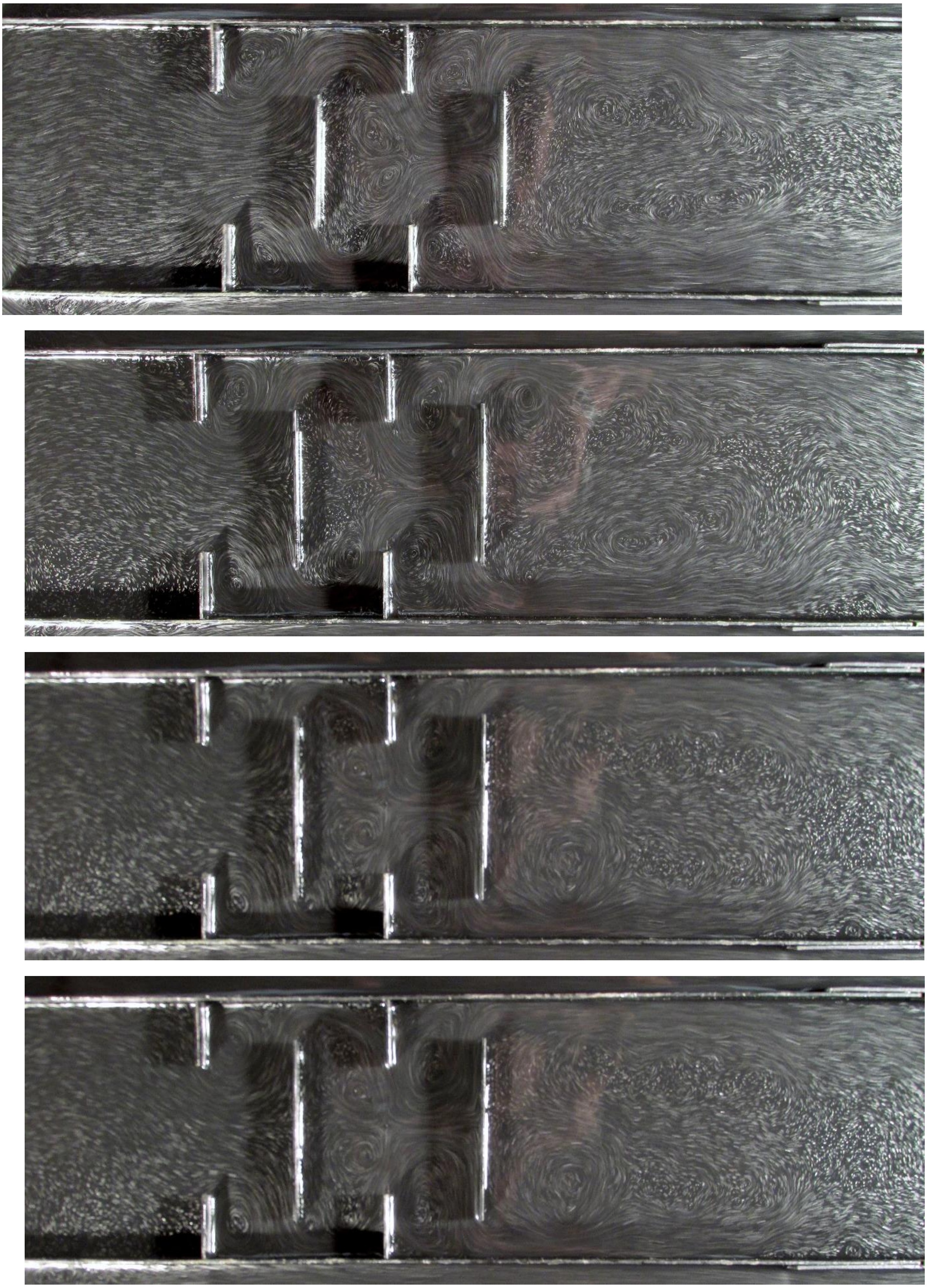

d/D

(a) 1.0

(b) 1.2

(c) 1.4

(d) 1.6

Fig 6: flow patterns for n=2, p/B=0.4

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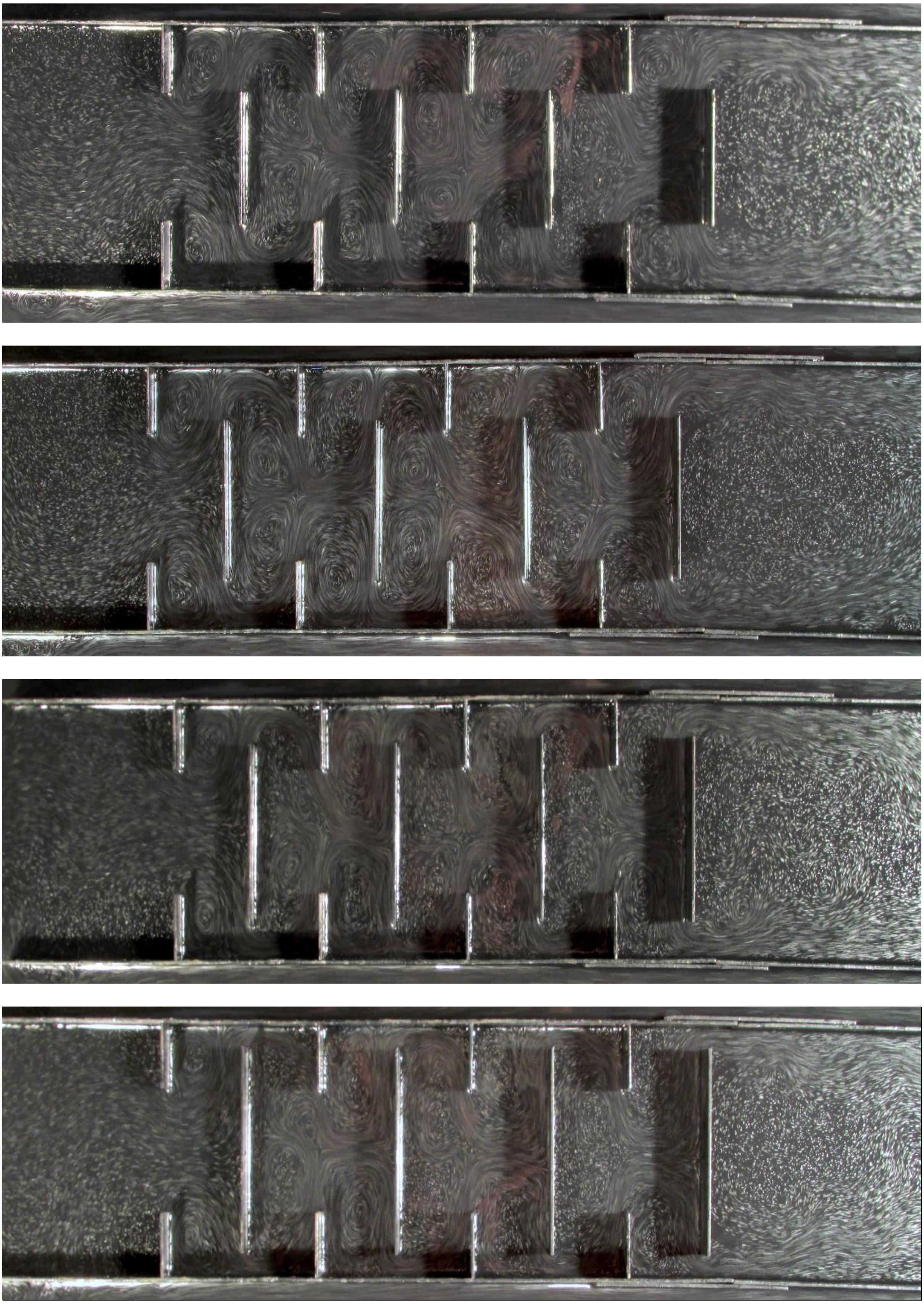

Fig 7: flow patterns for n=4, p/B=0.4

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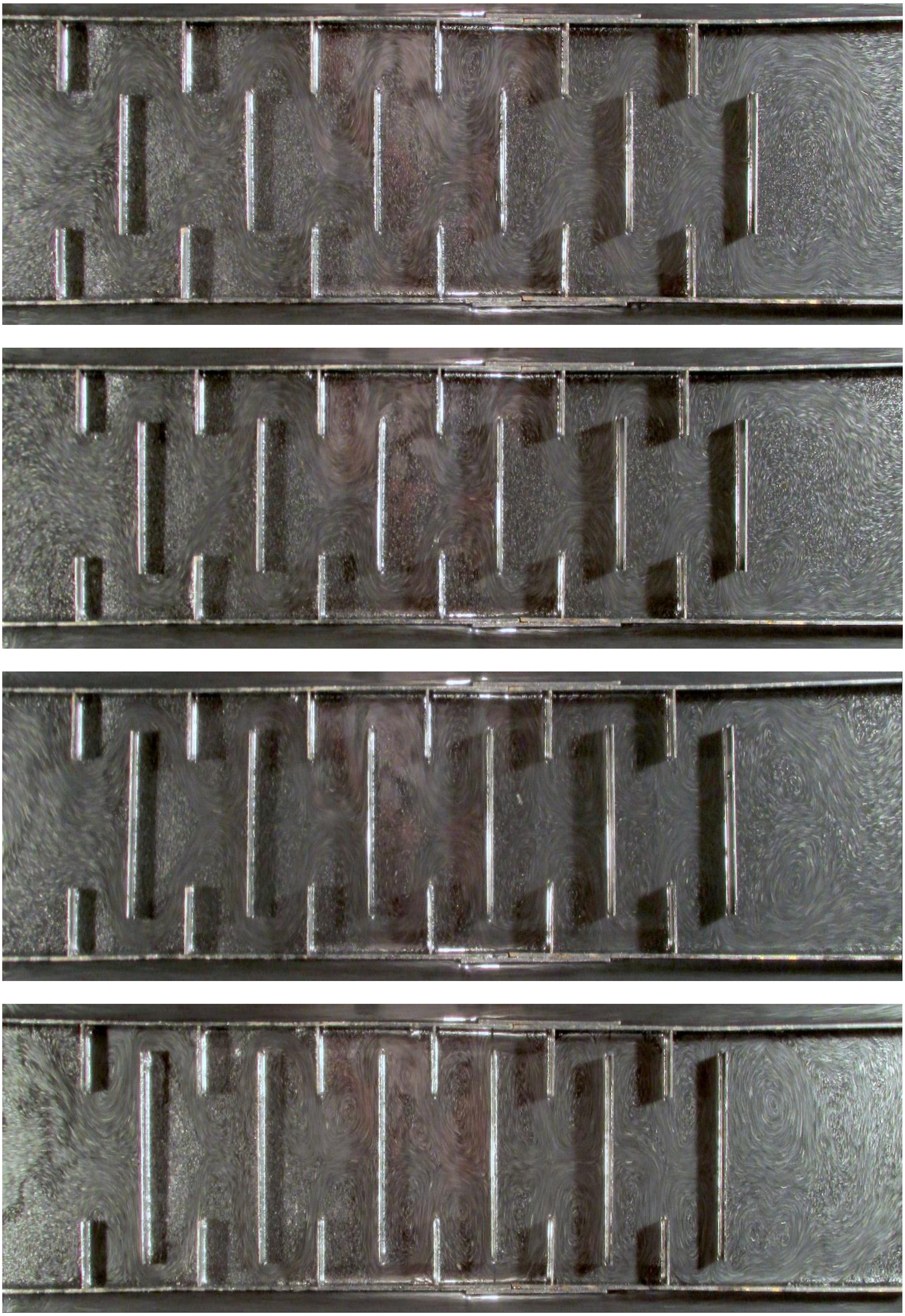

d/D
(a) 1.0
(b) 1.2
(c) 1.4
(d) 1.6

Fig 8: flow patterns for n=6, p/B=0.4

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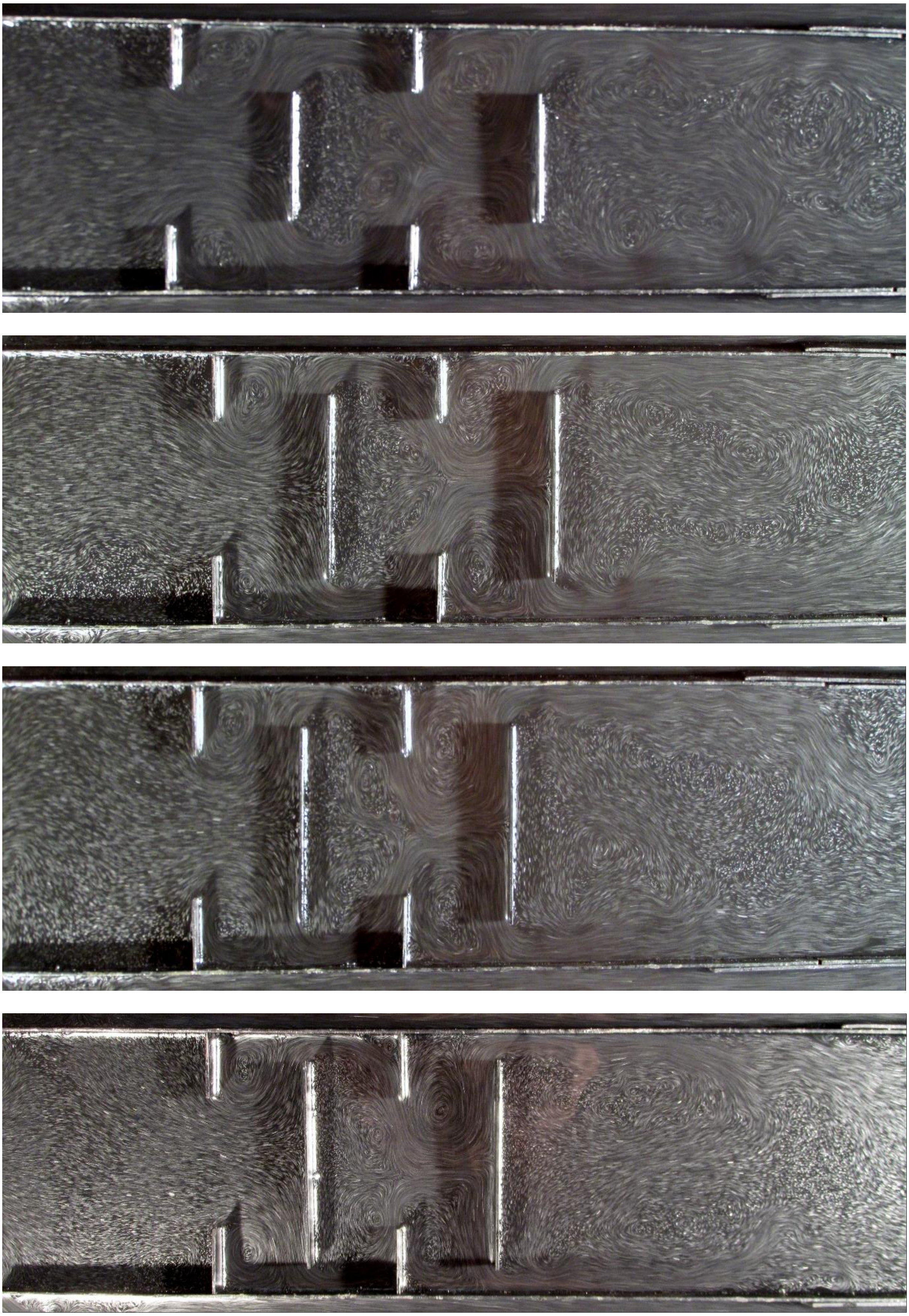

d/D
(a) 1.0
(b) 1.2
(c) 1.4
(d) 1.6

Fig 9: flow patterns for n=2, p/B=0.5

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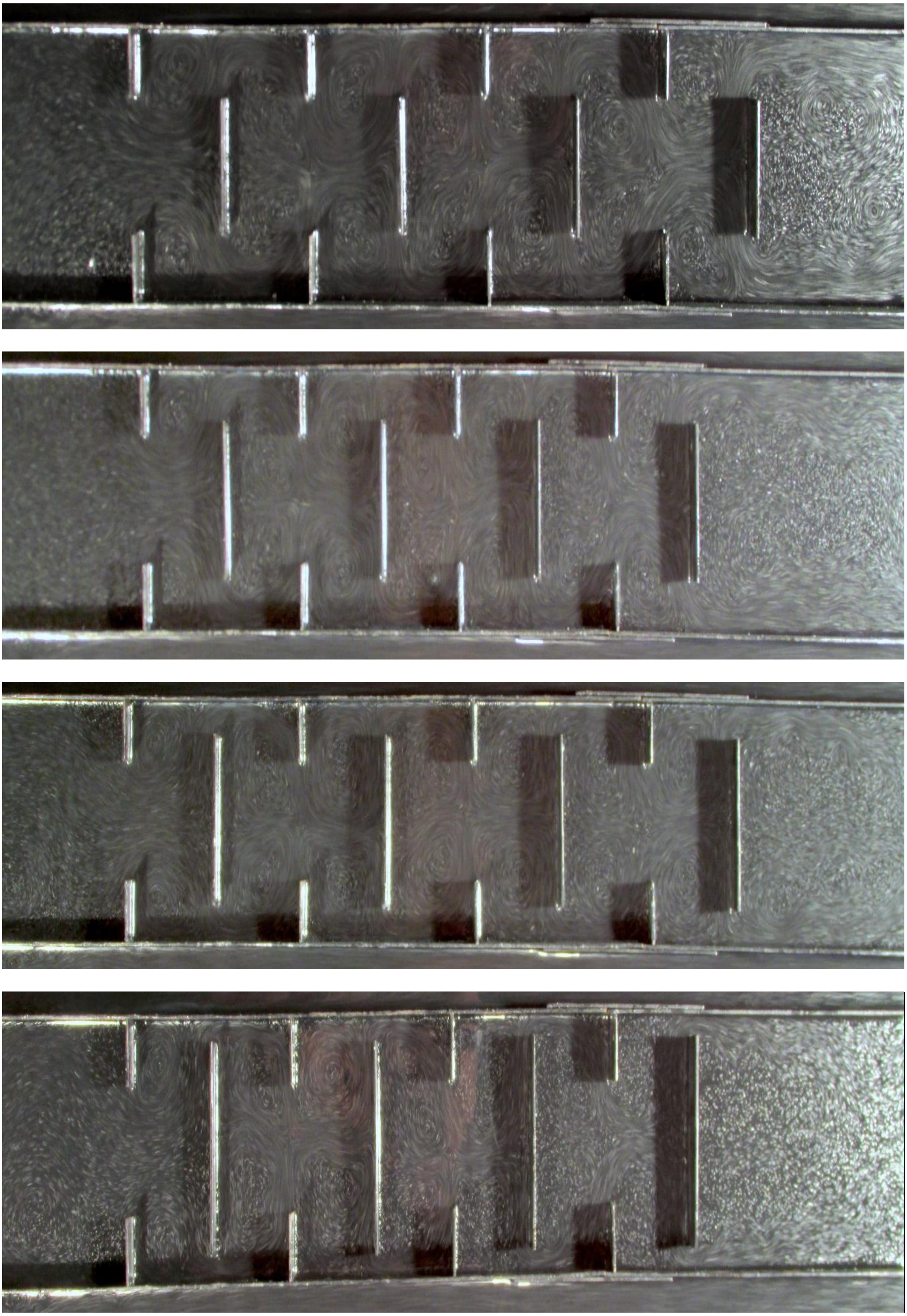

d/D
(a) 1.0

(b) 1.2

(c) 1.4

(d) 1.6

Fig 10: flow patterns for n=4, p/B=0.5

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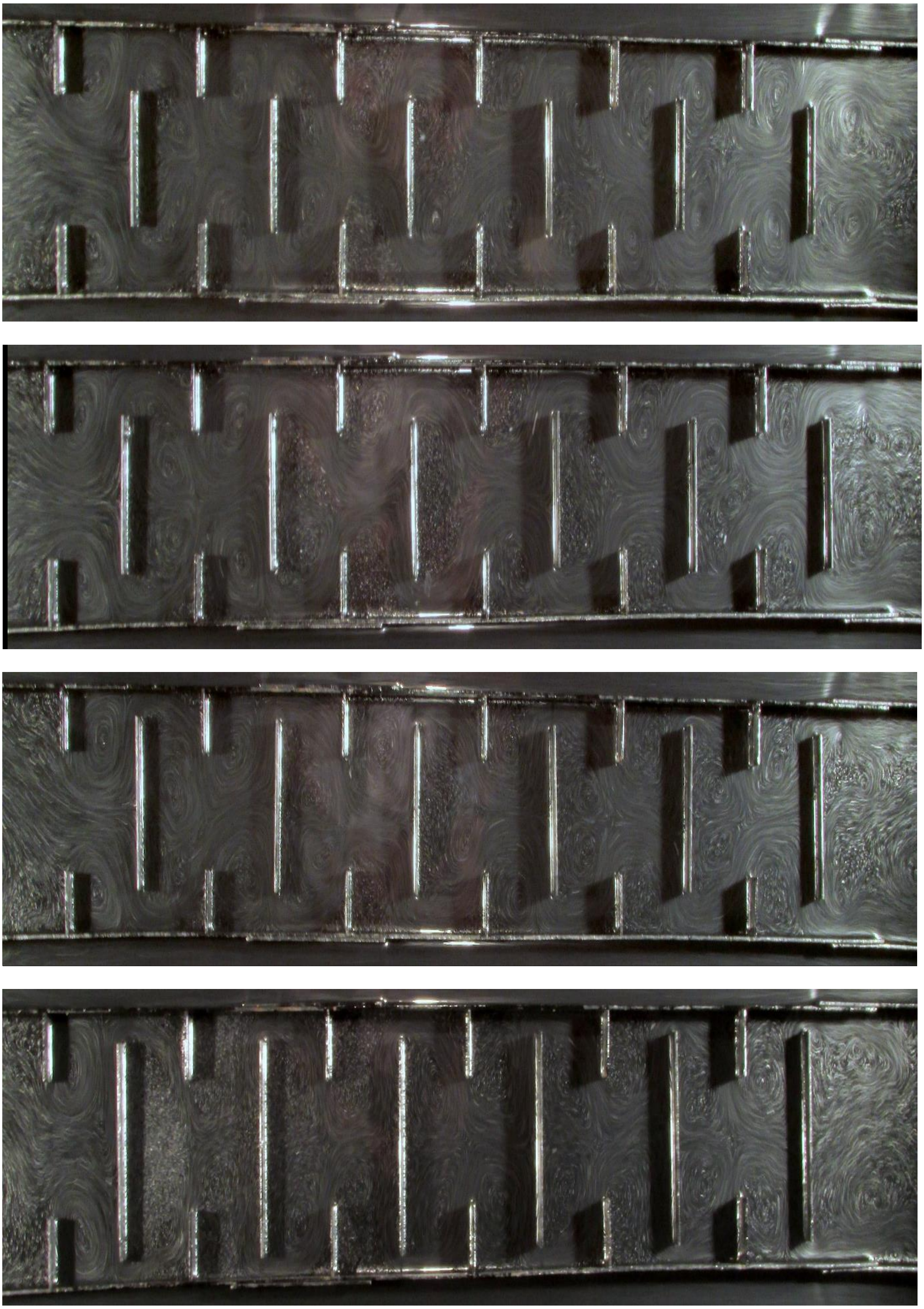

d/D
(a) 1.0

(b) 1.2

(c) 1.4

(d) 1.6

Fig 11: flow patterns for n=6, p/B=0.5