NUMERICAL STUDY OF THE EFFECT OF TRIANGULAR WINDBREAK ON TROUGH COLLECTOR'S DRAG FORCE

Qahtan A ABED[1], Wisam A ABD AL-WAHID[2], Dhafer MANEA[3]

In the present work, a numerical procedure to study the effect of the triangular windbreak on the drag forces of the parabolic trough collector (PTC) provided. Windbreaks are useful tools to reduce drag force. While common windbreaks are vertical walls, present work suggested an alternative triangular shaped hill put in the mainstream of flow. COMSOL Multiphysics v. 5.3 code used in the analysis of the trough solar collector. The results show that a reduction in drag forces may reach 55% of the original case (no-windbreak usage). Five different values of wind flow have been analyses. To achieve this aim, a 2D modelling of trough solar collector was carried out. The current work is the continuous work of the authors of studying the effect of windbreaks on troughs.

Keywords: Windbreak, drag forces, trough collectors.

1. Introduction

Energy consumption expanded every year as humans' life complications increased. Therefore, the need for new resources of power presented itself as a survival problem since extensive fuels are about to be consumed. Renewable energy can consider as the real and proper solution to that, where they have no side effect. One of the renewable energies devices is solar trough collectors (STCs). These collectors are kind of concentrating solar thermal application that transforms the solar energy into thermal energy. They have concentrated solar energy on a receiver tube where a fluid flows, which receives that energy to use it later in the production of power. The parabolic trough collectors (PTCs) can be applied in a wide range of applications such as industrial heat, electrical product, desalination, and space cooling, etc. Best location for troughs is open fields and deserts where they are subject to natural wind flow. More recent studies have confirmed widely that the airflow pattern on solar trough collector [1, 2 and 3]. Most solar plants built with trough solar collectors are located on flat ground, and they may be experiencing by some problems, such as wind flow [4, 5, and 6].

[1] Asst. Prof., Al- Furat Al- Awsat Technical University, Engineering technical college, Najaf, Iraq, qahtan77@yahoo.com.
[2] Asst. Prof., Al- Furat Al- Awsat Technical University, Engineering technical college, Najaf, Iraq, wsm19782000@gmail.com.
[3] Asst. Prof., Al- Furat Al- Awsat Technical University, Engineering technical college, Najaf, Iraq, dhafeer_manee@yahoo.com

Flow over trough found to affect heat losses from receiver to environment [7] and on aerodynamic loads of the trough collector which should be sustained by rigid structures [8, 9, and 10]. Heat losses reduction can be done effectively by using an evacuated tube covering the receiver. On the other hand, aerodynamic loads are shown to be reduced by windbreakers [11], or by shape modification of trough [9, and 10]. Small windbreaks put just in front of the receiver may have a substantial effect on heat losses reduction but not on aerodynamic loads [7]. A windbreak consists of a wall in front of trough studied experimentally [8], and numerically [7], but a windbreak of a triangular shape never been studied before, for the knowledge of the authors.

To know the wind flow field around the trough collector as well as around the receiver tube, it is necessary to simulate a solar trough collector for different wind speeds, which is the current study objectives. Triangular windbreak may be more natural to construct by using only a shuffle. Present work focuses on this kind of windbreak, as shown in Fig. 1, to study the effect on both heat transfer and flow pattern with different airflow speeds.

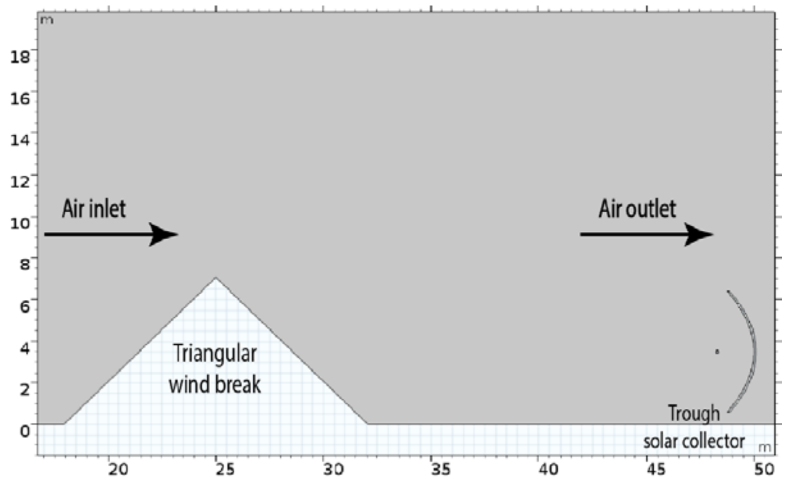

Fig. 1. The trough solar collector with windbreak of the present work.

2. Mathematical model:

The problem of present work need to solve continuity, momentum, and heat balance equations in two dimensions. The simulation has been implemented in steady state conditions. The flow assumed to be turbulent with the RNG $k-\varepsilon$ model since it is more responsive to the effect of rapid changes in flow variations. In order of verification needs, flow first assumed to follow the power law. In the other hand, present work considers uniform inlet flow as it found to be the worst case of flow [7]. The pressure at outlet assumed constant with no variation of velocity components. No-slip boundary conditions used at walls of a trough with symmetry upper boundaries. They are implemented as symmetry boundary conditions because the height of the domain exceeds 50m, thus the upper boundary has no effect on the calculation zone. Heat transfer losses are calculated from receiver to environment to find an effect of the suggested wall on a process.

The heat transfer boundary conditions imposed a constant wall temperature (350K), and the environmental temperature was 350K. A free ambient air confined the computational domain of the outside collector surface. The physical properties are assumed to change with the temperature only.

Wind is a violent mass movement of air, which is caused by the variation of pressure at a different position on the earth's surface [12]. Since parabolic trough collectors are usually arranged in parallel lines with each other and rotated each line in the center, the wind loads can generate great moments on the solar trough collector. Therefore, the triangular windbreak that reduces the effect of troublesome winds through creating a wind shadow.

3. Verification of present work and computational work

Present work focused on Euro trough solar collector, where specifications of trough tabulated in Table 1.

Table 1

Specification of Euro Parabolic trough solar collector.

Collector type	Parabolic trough collector (PTC)	
Absorber	Evacuated tube glass	
Surrounding fluid	Air	
Collector cost	Not more than 200 Euro/m^2	
Tracking system	The sun sensor	
	Mathematical algorithm	
Working fluid	Oil	
	Steam	
	Dependent of the application	
Collector size	12 m per element	
	100 - 150 m collector length	
	Aperture width	5.8 m
	focal length	1.71 m
Main structure	frame work	Steel
	Paint	Pre-galvanized
	Structure type	Light weight
Reflector	Material	Glass
	No.	28 facets per solar collector elements
Wind speed	Operation	14 m/s
	Stow	40 m/s

The present study is a modification work of that in [7], where a triangular wall replaces windbreak. This case study was verified with works of literature where it shows a good agreement.

In the numerical simulation, the type of grid is fundamental. The grid was generate by using COMSOL Multiphysics. The grid quality directly affects the accuracy of the simulation result. The build grid is uniform over the whole domain except near walls where grids extremely refined as shown in Fig. 2.

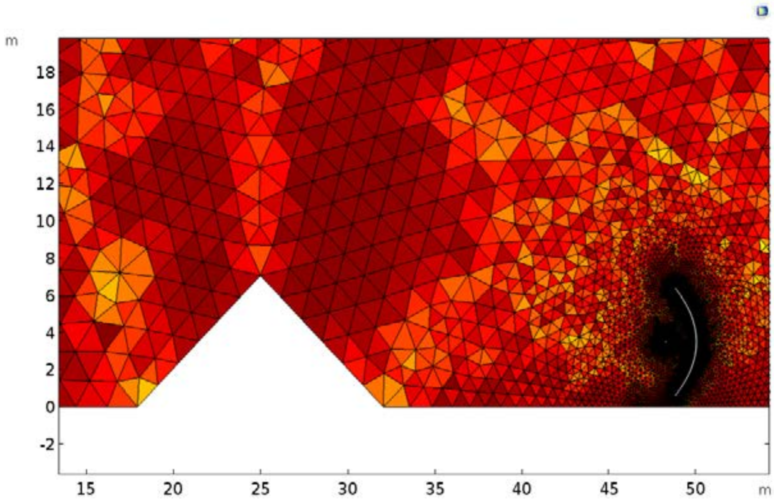

Fig. 2. Grid distribution in domain.

Problem solved by using COMSOL Multiphysics v 5.3 Program solver. Convergence of iteration of solution considered done as residual of all nodes to be less than 10^{-6}.

4. Results and discussions:

A numerical analysis was performed on the PTC with windbreak in order to describe the effect of wind speed on it. Five different values of wind speeds; 1, 2.5, 5, 10 and 15 m/s are implemented for every case. In figure 3, velocity distribution contours presented for the case of no-windbreak used at four different wind speed (1, 5, 10 and 15 m/s). It is the usual case for troughs, where they subjected to winds and modification for such case suggested here to reduce drag forces on troughs. The first trough is shown to take wind forces on behalf of all other troughs. This trough causes a wake area behind it and reduces the effect of wind on others due to divergent in wind direction.

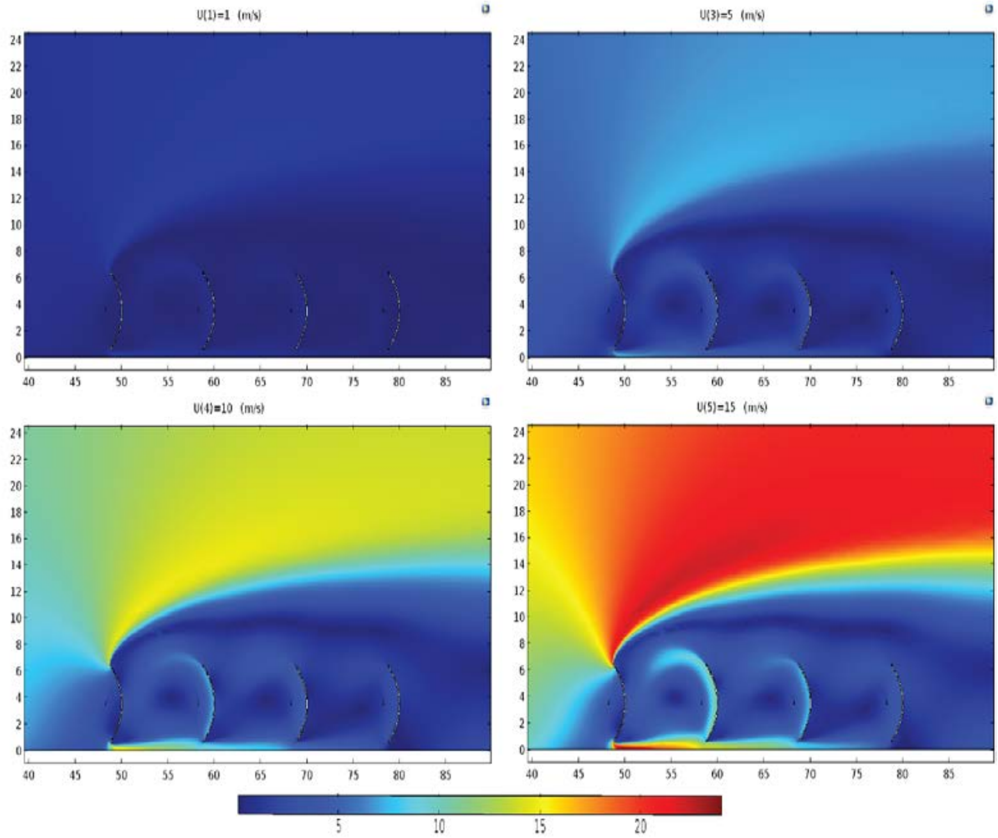

Fig. 3. Velocity contours for four troughs without windbreak at four different wind speed (1, 5, 10 and 15 m/s).

The wind was moving as shown in Fig. 3, the flow under the first trough, and cause an eddy at the second trough, which passes with smaller effect to the third one and such that very small eddy caused at last one. This behaviour has shown obviously in streamlines of flow in Fig. 4. This may be not enough to say that a significant reduction occurs, where the circulation on the second and third trough shown to be large enough to reach the boundary of the mainstream values. While the fourth trough shows very low wind speeds to be safe from the effects of the mainstream. It is a real idea to use obstacles as a guardian against drag forces. On the other hand, there is a high-speed zone beneath the first trough shown obviously in wind distribution. This zone expands until reach the third trough with gradually less magnitude.

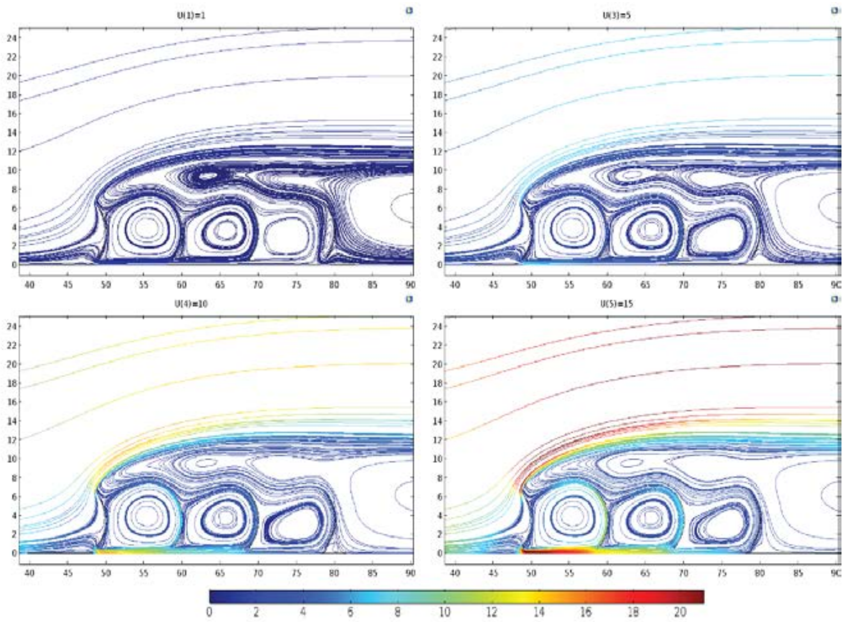

Fig. 4. Streamlines of flow for four troughs without windbreak at four different wind speed (1, 5, 10 and 15 m/s).

Fig. 5 shows pressure distribution in this particular case of no-windbreak usage. Pressure showed to concentrate on the first trough as a normal result for previous results with minor effect on rows of troughs laterally.

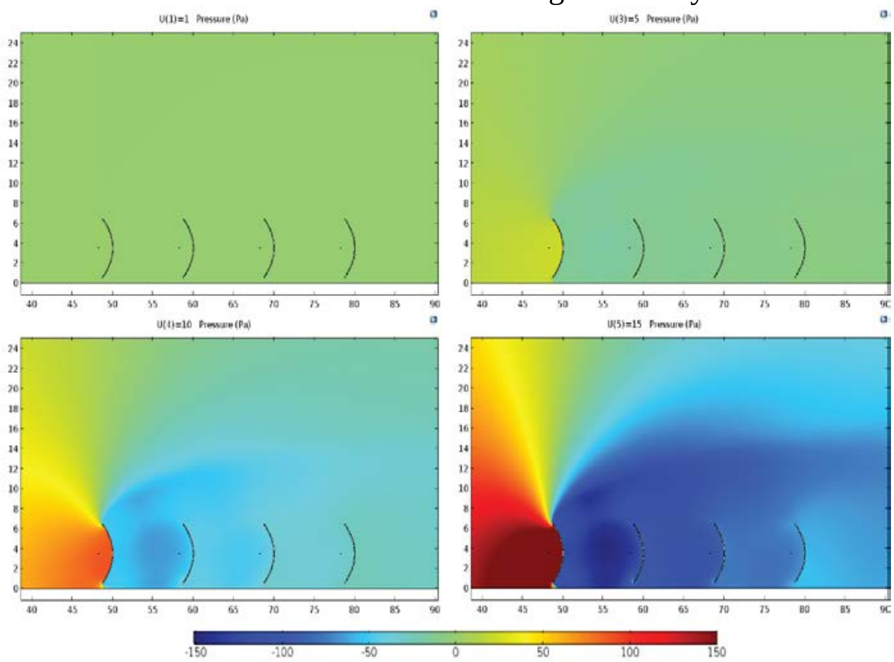

Fig. 5. Pressure distribution for four troughs without windbreak at four different wind speed (1, 5, 10 and 15 m/s).

Fig. 6 shows the values of drag coefficients numerically for the four troughs in the typical case (no using of windbreaks) as calculated by:

$$C_d = \frac{\sum Drag\ force}{1/2\rho U^2 A} \tag{1}$$

Results show a slight increase in drag coefficients values as the wind velocity increased from the values of 0.526 until reaching 0.535, which is logical since drag coefficients related mainly to the shape of objects immersed in fluids and the values of wind speed. Total force sure increased due to increase in $1/2\rho U^2$, but still causing a slight increase in drag coefficients.

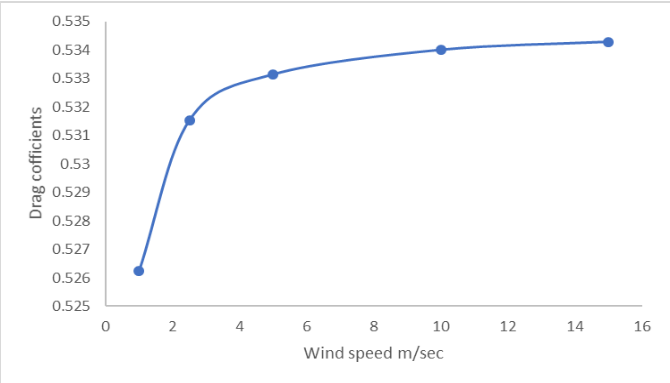

Fig. 6. Values of drag coefficients for four troughs without windbreak.

In Fig. 7, a triangular windbreak presented in the mainstream of airflow to diverge air pattern away from the troughs area. This strategy shown to work effectively since the value of airflow around troughs does not exceed half of the mainstream velocity. This behaviour has shown obviously in figure 8 where streamlines guided by triangular windbreak to flow away and to make a big arc above the troughs area. This behaviour affects directly on drag coefficients value, where a reduction of 55% occurred to these values. They indicate an excellent reduction in drag forces on the frame of solar troughs. Triangular windbreak taken is of 6 meters height, and since main characters controlling such work are the height of the windbreak and the separation distance between the windbreak and the trough, then another windbreak of height 10 meter taken.

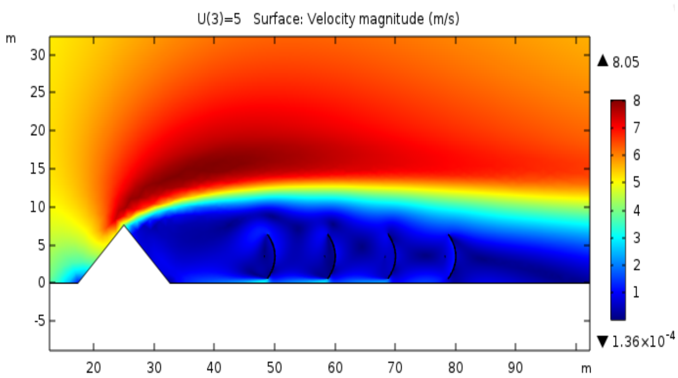

Fig. 7. Velocity distribution in case of using triangular windbreak.

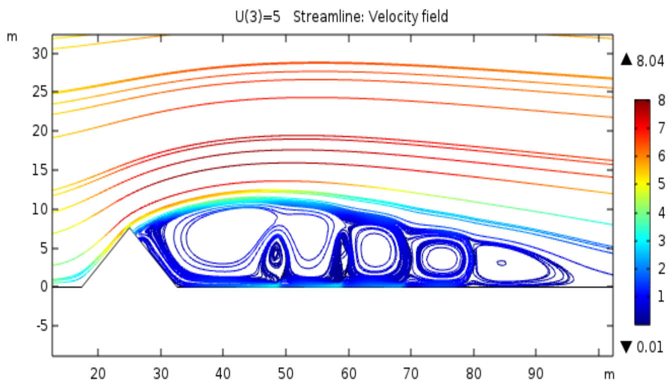

Fig. 8. Variation of the streamlines for four solar troughs with a windbreak.

Fig. 9 shows velocity distribution for which a higher windbreak (10 meters height) used. It shows the formation of a more significant wake area behind the windbreak compared to that of Fig. 7. Air shadow area may reach (in Fig. 7) 100 meters behind a windbreak, while in Fig. 9; wake area may progress to 120 meters. This wake area is the better place to distribute troughs rows without concerning high drag forces due to airflow.

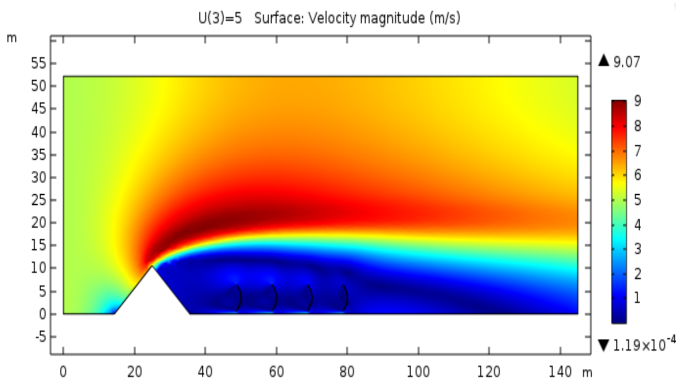

Fig. 9. Velocity distribution for four troughs and windbreak of 10 meters height.

Fig. 10 shows the comparison of drag coefficients values for the parabolic trough collectors with and without windbreak. As can be seen, the effect of using bigger windbreak on drag coefficients values, where increment reaches 63% of that without using a windbreak, and 8% less than that of 6 meters height windbreak. The results show more decrement in drag forces as windbreak height increase. They have dropped to more than 50% and this is a great gain to reduce the forces attached to the parabolic tough structures.

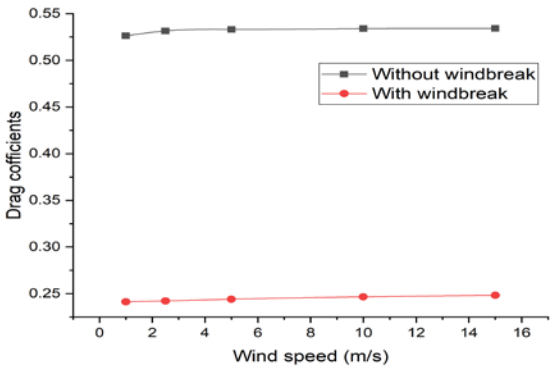

Fig. 10. Drag coefficients for four troughs, with and without windbreak.

In order to show the heat transfer losses from the collector, the calculated Nusselt number has been compared. Fig. 11. shows the comparison of the estimated Nusselt number for the collector with and without windbreak. According to this figure, the Nusselt values increase due to high wind speed. Besides, this figure shows in lower wind speed has the near values of Nusselt for both models. For given wind speed, the enhancement in Nusselt number caused by windbreak is reduced the heat losses from the collector.

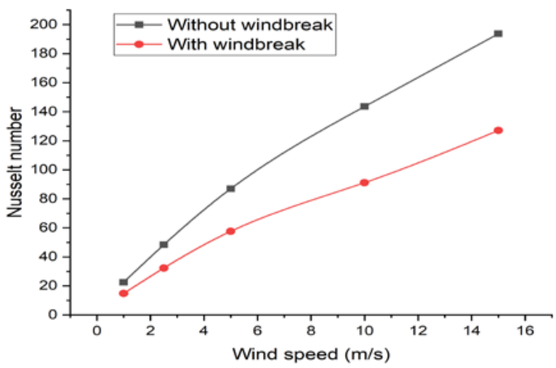

Fig. 11. Comparison of the Nusselt number versus wind speed for four troughs, with and without windbreak.

5. Conclusion

Present work presented numerically, the effect of using triangular windbreak on drag coefficients values. The two-dimension PTC analysis has been conducted with COMSOL Multiphysics CFD program. The airflow simulation around a trough solar collector shows, the different rotation zones can be seen on the wind flow of the trough collector. Windbreaks are necessary to avoid high drag forces on the frame of troughs. Vertical walls windbreaks commonly used in such cases, where they show to be expensive. Windbreak suggested here are a triangular shaped low hill made by a shuffle in the shape of the triangle. Results show a reduction of 55% in drag forces for a row of troughs. This reduction may suggest the validation of present work idea to be useful. The Nusselt number generally increases by increasing the wind speed over the parabolic trough collector with or without windbreak. Therefore, they lead to the reduction of heat losses transfer from the collector to the ambient.

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