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IMPACT OF CHANGING ABSORBER SHAPE ON AN AIR FLOW BEHAVIOR IN A THERMO-SOLAR CONVERTER

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ABSTRACT

In this paper, a two-dimensional numerical study of heat exchange by forced convection of an incompressible laminar flow in a solar air heater duct (SAH), which is equipped with a shoulder attached to the absorber, was performed. The impact of three locations of this shoulder and their three heights on friction losses, as well as the drag coefficient, the variations of velocity, and temperature at the exit section of the SAH, were analyzed for a volume flow rate in the range [20-80 m3/h.]. The results obtained numerically prove that the insertion of a shoulder on the absorber improves the heat transfer and the dynamics of the flow very significantly. An average temperature difference (inlet-outlet) of the collector of 23.51 °C at 29.94 °C and 50.64 °C at 67.53 °C is acquired respectively for the high and the low flow rates. This paper also showed that the height of the shoulder used can ensure an acceleration of the flow with an axial variation of the order of 1.25 up to 2.5 times (> twice) compared with the simple case.

Keywords: Solar Energy, CFD, Heat Transfer, Thermo-Solar Converter

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1. INTRODUCTION

A mere half hour of the solar radiation received by our planet is equivalent to the world's yearly energy requirement Kalogirou (2004). The solar energy can be used in various processes, such as heating, cooking food at home, generating electricity, etc. Due to the simple design of solar air heaters (SAHs), they are used to trap solar radiation, which can be used to heat ambient air or water under atmospheric conditions. However, the low heat transfer coefficient of the air leading to insufficient heat exchange between the absorbent plate and the fluid in the solar collector and therefore resulting in poor performance and thermal efficiency. Several techniques have been introduced in the dynamic air of the solar collector, for increasing the heat transfer between the air and the absorber Varun et al. (2007), Yadav and Bhagoria (2013), Bhushan and Singh (2010), Saim et al. (2010). For the improvement of its thermal performance, several studies have been carried out to modify the passage of the airflow by using a porous or finned absorber, a corrugated shaped absorber or an artificially rough absorber with ribs of different shapes., sizes, orientations and positions Sukhatme (1996), Hans et al. (2009), Yeh et al. (1998), Yeh et al. (2000), Gbaha (1989), Hachemi (1992), Saim et al. (2013), Benzenine et al. (2013), Nasiruddin and Siddiqui (2006), Ahmed (2012), Benzenine et al. (2013), Saim et al. (2013). Using other methods, many authors have investigated and reported various experimental and numerical investigations. Concerning the flow passages in SAH, for example, Labed et al. (2012) made a comparison on the performance of double-pass and single- pass solar collectors (without obstacles, with rectangular obstacles and with trapezoidal obstacles). A similar arrangement of a square shape offset absorbent plate was used in an indirect solar dryer by Youcef-Ali and Desmons (2005). Ozgen et al. (2009) carried out an experimental study to treat the thermal performance of double-pass air heaters in the presence and absence of aluminum boxes, arranged in staggered rows and in order. Experiments carried out showed that the efficiency for the case of solar air heater, with bottles arranged not in order, is higher than the other two cases due to the more turbulence and the presence of dead zones in the air heater. Regarding the corrugated-sheets technique, in a regular pattern, the plates are molded, with smooth corrugation or other type. These help to increase the heat transfer surface. For this technique, the study refers to the studies of Liu et al. (2007a), Liu et al. (2007b). Another study of the thermal performance of double-pass solar air heaters with differently shaped "flat and V-corrugated" plates was carried out by El-Sebaii et al. (2011a), El-Sebaii et al.(2011b). For porous type, such as plate with holes, metal sponges, etc. A porous absorbent plate can be used. Air is passed through the porous material, which helps to improve the heat exchange coefficient. The heat transfer surface will be increased due to the porosity; however, the pumping power will increase as the porosity is released. Here, the study give as examples the publications of Tong and London (1957), Bharadwaj et al. (1981), Aldabbagh et al. (2010), Omojaro and Aldabbagh (2010), Dhiman et al. (2012), Lalji et al. (2012), Gupta and Kaushik (2009), Languri et al. (2011), and Mittal and Varshney (2006). Regarding the technique of combining wire mesh with incorporated baffles, we refer to the work of El-Khawajah et al. (2011), El-Khawajah et al. (2015). The thermal performance of a SAH was ameliorated with a transparent honeycomb made of glass tubes by Zhang et al. (2009). Raschig rings were used by Öztürk and Demirel (2004) to control flow inside the SAH. The jet impingement type was studied by Chauhan et al. (2012) and Zukowski (2015). Overlapped glass plates were investigated by Selçuk (1971) and Sodha and Kumar (1984). The transpired type was studied by Badache et al. (2012), Chan et al. (2013), and Chan et al. (2014). For special designs as PV/T (Photo Voltaic/Thermal), there is an example the work of Solanki et al. (2009) and Kumar and Rosen (2011). Other studies have also been carried out on indirect-type solar drying systems, where the collector presents a main element of the dryer; the authors have confirmed that improving the efficiency of this system is directly related to the performance of the collector Dilip and Kumar (2004), Dilip (2007), Lyes and Azeddine (2003), Subarna et al. (2011), Ahmed-Zaïd et al. (2001).

From this research bibliography, it is seen that many solar collector improvement techniques have been proposed in the literature. Several studies have focused on the movement of air inside the solar dryer, and the way in which moisture and heat are evacuated. However, the integration of a shoulder as a geometric element attached to the absorber of the SAH is a new approach that has not been studied by earlier studies. Thus, this study addresses the effect of introducing a shoulder in the absorber to improve the performance of a flat air solar collector on the dynamic and thermal level. The influence of the location and height of this shoulder on the changes in temperature and velocity at the outlet of the collector are investigated. The absence of a shoulder was also treated as a comparison with the other cases and for different volume flow.

2. DESCRIPTION OF THE SYSTEM

In this study, the geometric dimensions of the problem studied are based on the experimental data published by Labed et al. (2009). This is a solar air heater (SAH) comprising a single transparent glass (5 mm), a matt black absorber (0.4 mm, galvanized steel) and an insulator (0.4 mm). The two-dimensional geometric configuration treated in the present study is shown in Figure 1

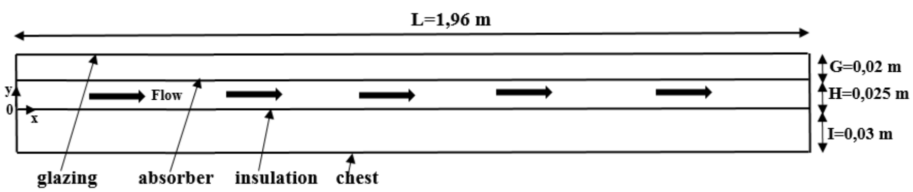

Figure 1 Descriptive diagram of the solar collector in our study

Figure 2 b, c and d). The simple case of Figure 2 a was also examined and compared with the other cases

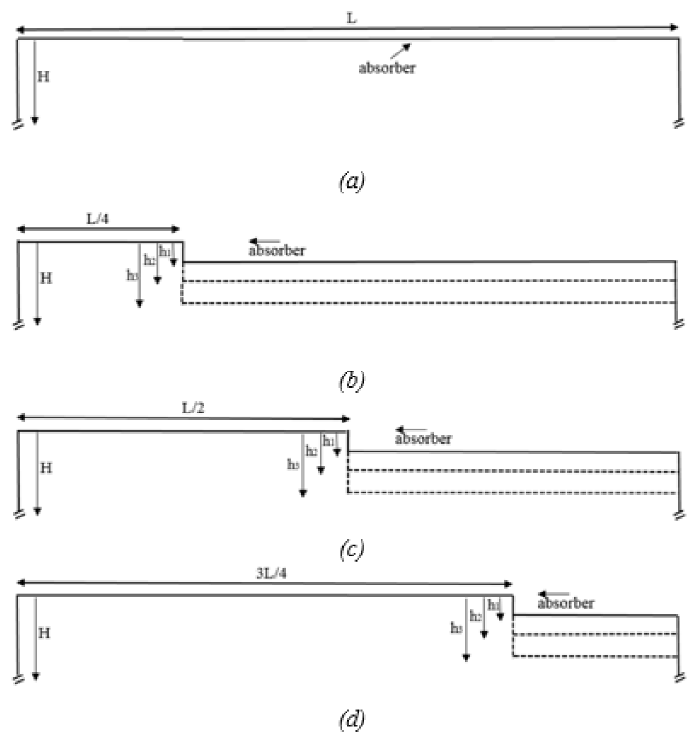

Figure 2 The cases treated: (a): simple case (without shoulder); with shoulder positioned: (b) at L/4 (Case 1), (c): at L/2 (Case 2), and (d): at 3L/4 (Case 3), with different heights

3. CONSERVATION EQUATIONS

The governing equations the air flow and the heat transfer in the solar collector plane namely: the equations of continuity, momentum and energy are given as follows:

Continuity:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{1}$$

Momentum Equation:

$$\frac{\partial (UU)}{\partial X}+\frac{\partial (VU)}{\partial Y}=-\frac{1}{\rho}\frac{\partial P}{\partial X}+\left[\frac{\partial}{\partial X}\left(\nu\frac{\partial U}{\partial X}\right)+\frac{\partial}{\partial Y}\left(\nu\frac{\partial U}{\partial Y}\right)\right] \tag{2}$$

$$\frac{\partial (UV)}{\partial X}+\frac{\partial (VV)}{\partial Y}=-\frac{1}{\rho}\frac{\partial P}{\partial Y}+\left[\frac{\partial}{\partial X}\left(\nu\frac{\partial V}{\partial X}\right)+\frac{\partial}{\partial Y}\left(\nu\frac{\partial V}{\partial Y}\right)\right] \tag{3}$$

Energy equation:

$$\rho_0 C_p\left[\frac{\partial (UT)}{\partial X}+\frac{\partial (VT)}{\partial Y}\right]=\left[\frac{\partial}{\partial X}\left(K\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial Y}\left(K\frac{\partial T}{\partial Y}\right)\right] \tag{4}$$

Average friction coefficient:

$$\overline{Cf}=\frac{2\bar{\tau}_w}{\rho .U^2} \tag{5}$$

where τ ̄_wis the average shear rate at the wall, U the average axial velocity and the density of the fluid.

Drag coefficient:

$$Cd=\frac{2\Delta p}{\rho U_0^2}\left(\frac{A_f}{A_0}\right) \tag{6}$$

Where Af and A0 are respectively the fluid flow cross-section and the bathed surface while Δp represents the pressure loss between the ends of the pipe. The simplifying assumptions corresponding to this mathematical model are as follows:

- Stationary and two-dimensional flow is considered laminar
- The heat flow applied to the top wall is uniform
- The thermophysical properties of the solid and the fluid are considered constant
- The temperature and velocity profiles at the entrance of the collector are assumed constant

Boundary Condition

Uniform velocity and temperature are introduced at the entrance of the collector while atmospheric pressure is applied at the outlet. The lower wall is isolated while a radiative flux is applied to the wall of the absorber. This study was carried out in the range [20.80 m3 / h.] of the volume flow

Numerical Modeling

The governing equations are solved on a staggered grid using a finite volume method Patankar (1980). The Fluent commercial code is used and the SIMPLE algorithm Patankar and Spalding (1972) is applied for velocity-pressure coupling; to discretize the convective terms, the second order QUICK scheme is used.

Mesh Sensitivity Analysis

A refined and concentric mesh in the vicinity of the absorber and the insulator in order to properly capture the strong variations of the gradients was applied.

The sensitivity of this mesh on the results is examined by carrying out a series of tests on the six grids 1000, 3000, 6000, 10000, 15000 and 21000. The relative error is obtained for the results of the maximum speed of the axial component., as well as the temperature at the outlet of the manifold, are presented in Table 1.

Table 1 Relative errors for outlet temperatures and maximum axial velocity obtained for the different grids tested

	1000	3000	6000	10000	15000	21000
T_{out}	323,439	323,478	323,485	323,490	323,493	323,497
Error%	-	0,0121	0,0021	0,0013	0,00105	0,00108
U_{max}	12,971	13,178	13,216	13,230	13,235	13,238
Error%	-	15,706	0,2925	0,0988	0,0442	0,0227

Finally, we have chosen the mesh with 15000 elements, which allows to obtain solutions with a minimal error.

Model Validation

Before treating our cases, we started by comparing our results with those obtained by Labed et al. (2009), by adopting its conditions used on a single-pass solar air sensor.

The comparison in terms of temperature variation at the outlet of the collector as a function of the flow rate shows good agreement with their experimental and theoretical results (Figure 3).

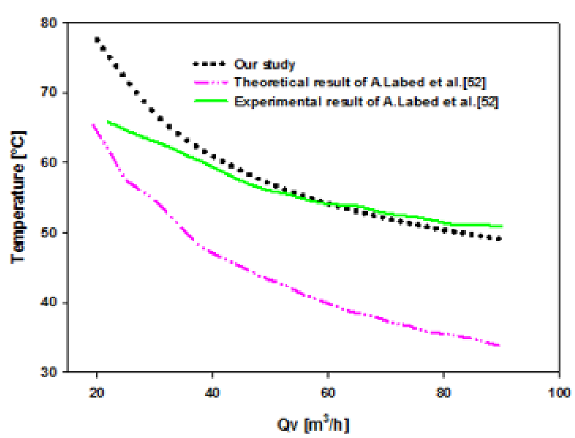

Figure 3 Variation and comparison of the outlet temperature as a function of the flow rate

4. RESULTS AND DISCUSSION

A computational analysis has been performed to see the effects of shoulder attachment onto the absorber in solar air heater duct at different volume flow rate and temperatures.

Figure 4(a, b and c) clearly shows the change of the outlet temperature for different heights and locations for different cases and as a function of volume flow. As shown from general form of the result that temperature values are decreased with increasing of volumetric flowrate as expected. Difference among temperatures is diminished from case 1 to case 3. It should also be noted that the lowest temperature values are recorded in the absence of the shoulder and that the outlet temperature becomes higher by increasing the height of the shoulder.

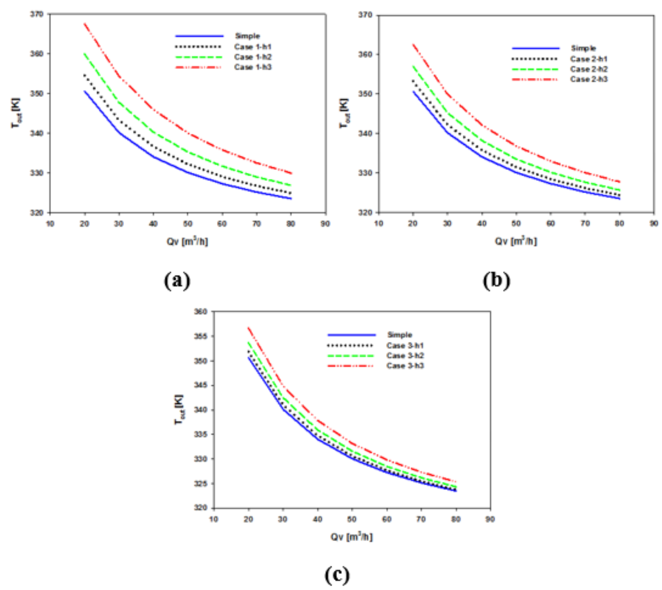

Figure 4 Evolution of the outlet temperature of the collector for different flow rate, different heights and locations: a) Case 1, b) Case 2 and c) Case 3

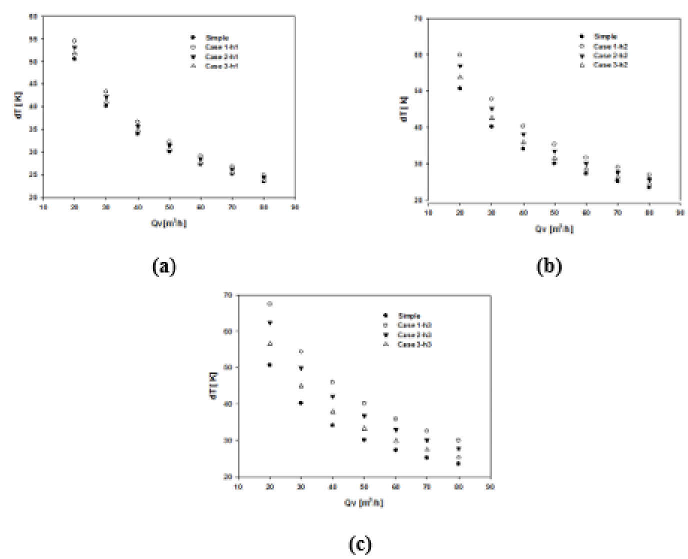

Figure 5 Variation of the temperature difference (input-output) as a function of flow rate with the different locations and heights: a) h1, b) h2and c) h3

(Figure 5 a, c) shows the downward variation of the temperature gradient (input-output) with the increase in flow. It is advantageous to use a low flow rate in order to prolong the exchange time. This indicated an important and thereafter a good temperature difference between the input and the output of the collector. Comparing the three figures as (Figure 5 a, c), it is observed that as the height increases more, the difference in temperature between cases becomes greater. This is especially visible in the vicinity of lower flowrate.

Table 2 shows the differences in minimum and maximum temperatures, respectively, corresponding to the high and low flow rates (80m3/h and 20m3/h) for the different locations with different heights and for the simple case for comparison. It is very clear that the neutral case is that of the simple case and the presence of a shoulder, especially with an advanced positioning, results in more heat transfer enhancement. Increasing the height of the shoulder increases the exchange of the surface and therefore, it contributes to the heat transfer enhancement at any position.

Table 2 Minimum and maximum temperature differences for the different cases treated

Simple case			Position 1 : L/4		Position 2: L/2		Position 3: 3L/4	
			Case 1		*Case 2*		*Case 3*	
dT_{min}(80)	dT_{max} (20)		dT_{min} (80)	dT_{max} (20)	dT_{min} (80)	dT_{max} (20)	dT_{min} (80)	dT_{max} (20)
23,51	50,64	**h1**	24,89	54,59	24,37	53,25	23,76	51,86
		h2	26,85	59,98	25,66	56,97	24,36	53,7
		h3	29,94	67,53	27,75	62,54	25,36	56,67

The variation of the coefficient of friction along the pipe provided with a shoulder placed in the middle (Case 2) is shown in (Figure 6 a, b). Thus, (Figure 6 , a) shows this variation for the greatest height, h3, and for three different volume flow rates (20, 50 and 80 m3/h). Also, (Figure 6, b) illustrates this variation for the same volume flow rate (50 m3/h) and for the three heights (h1, h2 and h3). As shown from the figures, the coefficient of friction is very low in the lower portion, and shows a drastic increase from the location of the shoulder. By passing this zone the coefficient takes constant higher values. It is also to be noted that the friction forces decrease with the increase of the velocity of the flow (Figure 6, a) and increases with the increasing of the height of the shoulder (Figure 6, b).

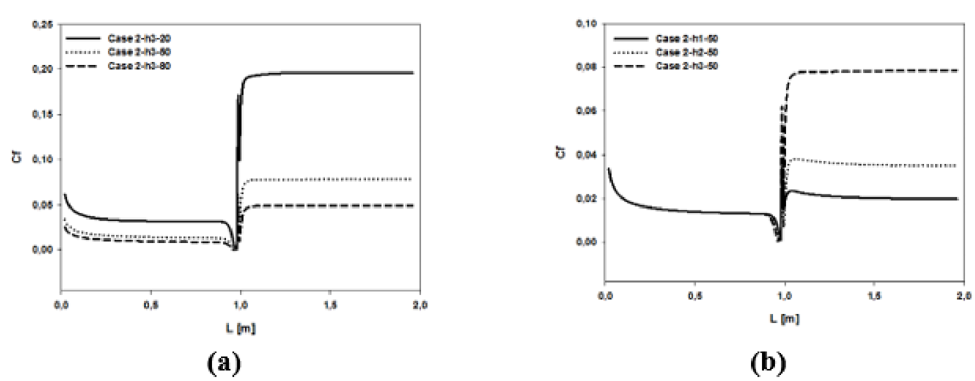

Figure 6 Evolution of the coefficient of friction along the absorber provided with a centered shoulder (Case 2) a) for different velocities and a constant height h3, b) for different heights and a constant velocity

Figure 7 gives the evolution of the ratio of drag forces compared to the simple case. It can be seen from the figure that the increase in the drag coefficient ratio is proportional to the height of the shoulder. Also, the losses generated by the first two heights (5 and 10 mm) are not very significant if it is compared to the case h3 (15 mm) for any locations. Moreover, a large shoulder (h3) placed at the entrance of the channel (Case 1) can result in a ratio of more than 100 times compared to the case without a shoulder., and therefore, for this study, presents an unfavorable case (not recommended).

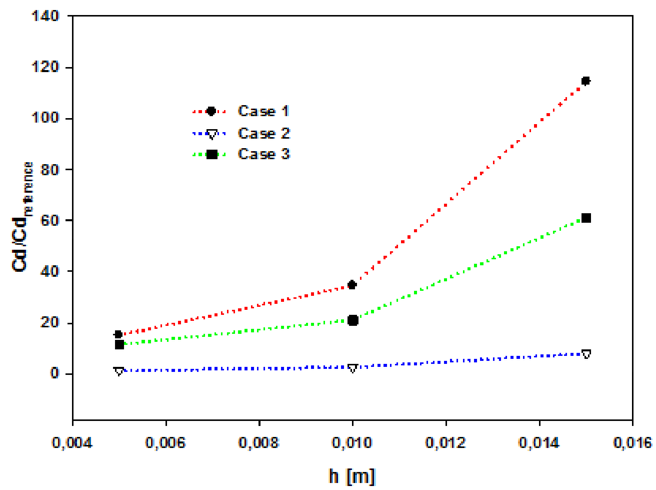

Figure 7 Evolution of the drag forces ratio according to the different heights

The presence of a shoulder in the air passage section results in a sudden narrowing of the passage section and therefore, it contributes to increase the ratio of the axial velocity to the inlet velocity as shown in Figure 8. From the fluid mechanics point of view, presence of the shoulder can help to accelerates to flow to increase the kinetic energy. Thus, heat transfer is increased with increasing of this kinetic energy.

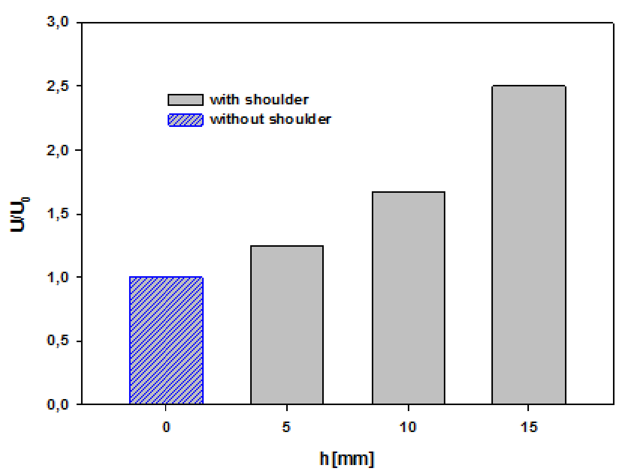

Figure 8 Evolution of the velocity ratio in the presence and absence of the shoulder

This acceleration of the air is very significant, and according to the type of application considered, for example the solar collectors used in the drying system, we see that the presence of a shoulder increases the circulation of air at the inlet of the drying chamber, and thus contributes to better air échapement wet at the exit of the chimney.

5. CONCLUSION

A numerical analysis, using the Fluent software, of heat transfer by forced convection of a laminar air flow in a flat solar collector was conducted. The analysis of the insertion impact of a shoulder on the absorber and the dynamic and thermal structure were studied for three heights and three locations in comparison with the simple case. Based on the results, it should be noted that:

- The addition of a shoulder in the system increases the exchange surface and reduces the passage section, which consequently improves the thermohydraulic efficiency of the system compared to the case without a shoulder.
- The temperature (inlet-outlet) of the collector is significantly low, ranging from (23.51 (simple case) up to 29.94 ° C (Case 1-h3)) for high flow rates. Then for low flows, it can reach (50.64 (simple case) up to 67.53 ° C (Case 1-h3)), so an interest is carried for these low flows which ensure more time of exchange.
- The use of one of the highest heights maximizes the temperature at the exit, but, on the other hand, considerably increases the friction and the drag.
- In order to increase the velocity ratio (U / U0) and accelerate the air at the output of the collector, the choice of the greatest height h3 makes it possible to obtain a gain of approximately 250% compared to the simple case.

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