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Numerical Simulation and Optimization Design of the Annular Mechanical Foam Breaker

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A B S T R A C T

The annular foam breaker is one which uses the vacuum and shear force generated by the Coanda effect to break foam. The pressure distribution directly affects its performance. So an investigation on the flow characteristics inside the annular foam breaker is important to optimize its structure. In this paper, the computational fluid dynamics (CFD) code, FLUENT, is employed to simulate the flow phenomena. The effect of various geometric parameters on the pressure distribution inside the annular foam breaker has been evaluated, including the width of the annular slot, the Coanda surface radius and the diffuser dimensions, etc. The numerical results show that the optimum value of the annular slot d = 0.5mm, the Coanda surface radius r = 20mm, the diffuser angle θ=6°, and the ratio of the diffuser length to radius is more than 14. Based on these analyses, an optimum structure of the annular foam breaker was designed and tested in the well bore flow simulation loop laboratory equipment. Compared with the old ones, the foam-breaking efficiency of the optimized annular foam breaker is improved from 71.16% to 86.58%, which increases by some 22.61%.

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1. INTRODUCTION

In recently years, foam has been used as a circulating medium to remove cuttings from the borehole in drilling oil and gas wells. Stable foam drilling is not only normally faster than conventional mud drilling but is indispensable in areas where the supply of water is limited or when drilling through cavernous formations into which the drilling mud flows and becomes lost. Moreover, foam has a high carry capacity and a relatively small volume of air is required for foam drilling. The expense of the equipment for a given size well is greatly reduced over that of using air alone [1-2]. However, major disadvantages of the air-foam drilling system are that after returning to the surface the foam remains stable and requires a long period of time to dissipate back to the volume of the original liquid. So, an extremely large pit is required to contain the foam to allow sufficient room for cuttings and for the foam to dissipate. When there is not sufficient capacity to accommodate the increased volume of foam, it will overflow and result in pollution. Moreover, the foam can only be used once if it cannot be broken down fast enough. It will needs enormous volume prepared foam liquid and consumes abundant of water and ingredient additives, which made the foam drilling cost increase greatly [3-4].

Various types of equipment and techniques have been employed to break foam including both chemical and mechanical methods [5-7]. Chemical methods employ various chemical defoamers to break foam including silicone oils, non-ionic surfactants, etc [8-9]. It is an effective method and has been used widely in foam drilling projects. However, defoamers have the disadvantage of changing the chemical and physical properties of the system. It will pollute the foam surfactant and reduce its foamability that the foam drilling fluid cannot be recycled. In addition, the foam drilling fluid needs of a large number of defoamers, which greatly increased the drilling cost. In view of these facts, foam-breaking by a mechanical force is desirable. And a number of mechanical foam breakers have been proposed over the years such as high rotate centrifugal foam breaker, foam–breaking cyclones, and air jet breaker, etc [10-15]. However, most of these breakers are hardly practical for foam-breaking operation in high-rate gas bubbling systems of foam drilling fluid. How to effectively break foam continues

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to be the major problem of foam drilling technology, and the search for higher performance devices continues to be the subjects of much current research.

Recently, the annular mechanical foam breaker has been developed as a new type of foam breaker, which is designed mainly based on Coanda effect [16-17]. It turns out to be one of the most effective ways since it combines two effects of vacuum and shear force to break foam. In this paper, the flow characteristics inside the annular foam breaker were simulated numerically, and the effect of various design parameters on its performance was studied. A commercial CFD code FLUENT with a preprocessor, GAMBIT has been used to conduct the numerical analysis on the annular foam breaker. Based on these analyses, an optimum structure of the foam breaker was designed and tested in the well bore flow simulation loop experimental stand [18].

2. THE ANNULAR FOAM BREAKER

Schematic diagram of a typical annular foam breaker is shown in Fig.1. Pressurized air is supplied via the air channel to the slots between the foam receive chamber and the jet body. The air-stream flows through these slots at high speed and thanks to the Coanda effect, adheres to the convergent slots wall (Coanda surface), enters the narrowest section called the throat and continues along the walls of the diffuser. Such a high speed flow causes the pressure nearby decrease. When the foam drilling fluid flow through this low pressure region, the bubble will be burst as a result of the quick changed in pressure. On the other hand, the high speed air-stream interacts with the relatively low speed foam fluid in the foam receive chamber, and then mix all along the length of the jet body and the diffuser. The difference in velocity between the air-stream and the foam drilling fluid makes the momentum transfer from the high velocity air to foam fluid, which sets up a strong shear force to collapse the bubbles.

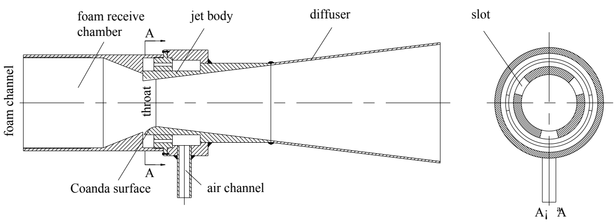


Figure 1. Schematic of annular foam breaker

The numbers of the slot are designed according to the gas supply conditions. If there is enough gas flow rate, it can be made one annular slot, which is named the annular foam breaker.

The study of the annular foam breaker is a complex problem because many parameters can affect its performances including the geometrical parameters of the Coanda surface, the length and the angle of the diffuser, the size of the slots, etc. Here, we adopt the Computational Fluid Dynamics code to analyze the flow phenomena inside the annular foam break and to improve its performance.

3. NUMERICAL MODEL

CFD commercial package, FLUENT6.0, is used as the tool to simulate the flow characteristics of the annular foam breaker. The grid generation is done using the preprocessor available with FLUENT namely GAMBIT. 2D axial symmetric model with quadrilateral mesh element is chosen in order to reduce computer costs and data manipulation time as shown in Fig.2 (a).

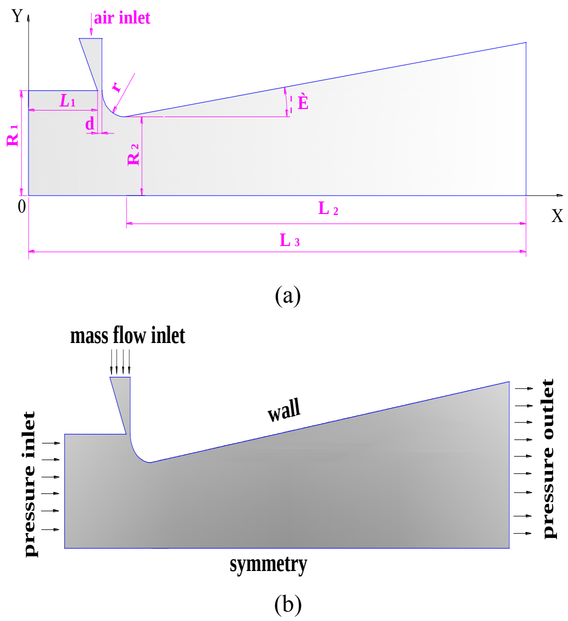


Figure 2. The analytical model of the annular foam breaker: (a) Analytical model, (b) Boundary conditions.

The dense meshes are preset at the area of high flow rate and high pressure gradient. The solving method is couple implicit. The realizable k-ε turbulence model is selected while the standard near wall function is used in the near wall treatment. The energy equation is included, while the fluid property is defined as an ideal gas, Sutherland's law for variation of viscosity with temperature. Fig. 2 (b) illustrates the boundary conditions for numerical analysis. The mass flow inlet and the pressure inlet are applied to the boundary of the air channel and the foam channel, respectively. The initial mass flow rate at the inlet is about 0.20kg/s. Since the foam burst process is very complicated and difficult to simulate, the pressure inlet boundary is set to atmospheric conditions to simplify the calculation. The structural parameters used in the initial simulations are as follows: L_3=600mm, R_1=50mm, R_2=30mm, r=15mm, d=0.5mm, θ=10°, α=18, where L_3 is the length of the foam breaker; R_1, R_2, r are the radius of the foam channel, the radius of the throat plane and the radius of the Coanda surface respectively; d is the width of the annular slot; θ is the diffuser angle and α is the length-radius ratio of the diffuser:

$$\alpha = \frac{length}{radius} = \frac{L_2}{R_2}$$

In which L_2 is the diffuser length, as shown in Fig.2 (a).

4. RESULTS AND DISCUSSION

Fig.3 shows the velocity distribution contours inside the annular foam breaker. The velocity reaches a maximum near the wall and then rapidly decreases to a uniform and constant value in the center of the foam breaker. The air-stream flows through the annular slots at a high speed and adheres to the Coanda surface and the wall of the diffuser, which causes the static pressure nearby to decrease, as shown in Fig.4.

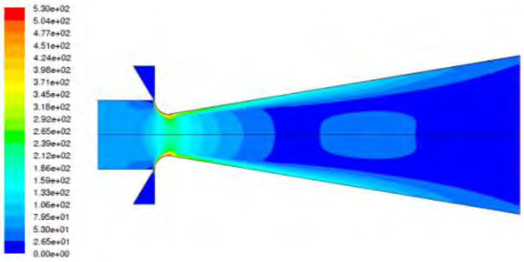


Figure 3. Velocity contours inside the annular foam breaker (m/s)

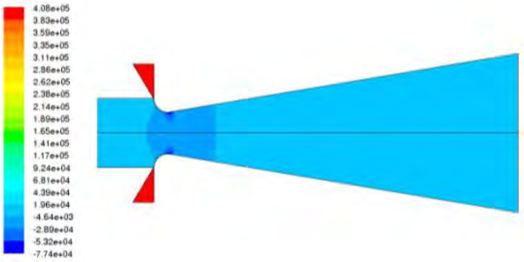
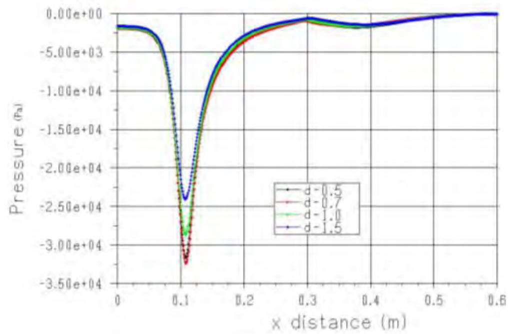


Figure 4. Static pressure contours inside the annular foam breaker (Pa)

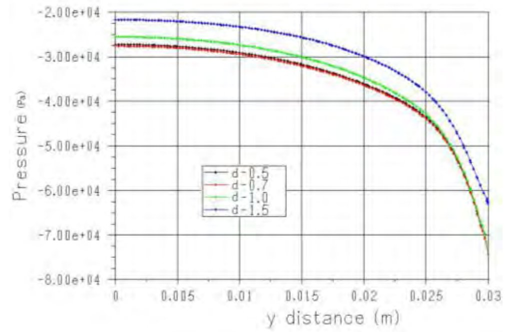
The lowest pressure is about -77.4 kPa, which is located at the throat plane nearby the Coanda surface. When the foam fluid flows through this negative pressure region, it will be burst under the effect of the pressure difference.

4.1. Effect of the Annular Slot Width "d"

The width of the annular slot, termed as "d", is varied from 1.5 mm to 0.5 mm while other parameters and the operating conditions are fixed. It is found that the static pressure along the central axis of the annular foam breaker at y=0 section decreases rapidly to a negative value at the throat and then gradually recovers along the diffuser to ambient pressure as shown in Fig.5(a). The magnitude of the static pressure near the throat decreases with the value of d decrease from 1.5 mm to 0.7 mm. But further decrease in the value of d gives roughly the same pressure distribution (from 0.7mm to 0.5mm). The pressure profiles at the throat plane are also confirming it as shown in Fig 5(b). The value of d adopted in the following study is 0.5mm.



(a)

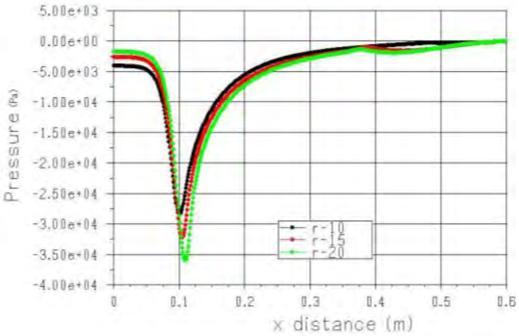


(b)

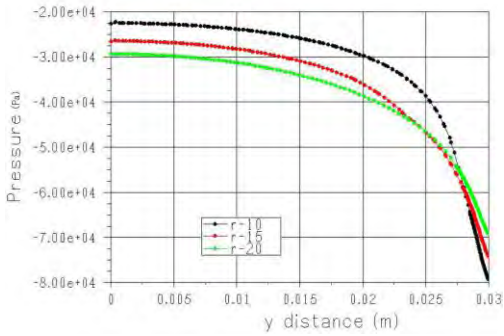
Figure 5. Static pressure profiles for various "d": (a) Static pressure profiles along the axis (y=0), (b) Static pressure profiles at the throat section.

4.2. Effect of the Coanda Surface Radius "r"

Keeping the other parameters unchanged, different r values has been investigated in order to study the effect of the Coanda surface radius on the pressure distribution. The calculation results are given in Fig.6. With the value of r increase from 10mm to 20mm, the magnitude of the negative pressure decreases from -28 kPa to -36 kPa at the y=0 section near the throat. Fig.6 (b) shows the static pressure reaches a minimum near the wall and then rapidly increases to a uniform value in the center of the foam breaker. Though the minimum pressure near the wall increases with an increase in the value r, the pressure at the most other regions is reduced. Thus the best value of the Coanda surface radius r is 20mm.



(a)



(b)

Figure 6. Static pressure profiles for various “r”: (a) Static pressure profiles along the axis (y=0), (b) Static pressure profiles at the throat section.

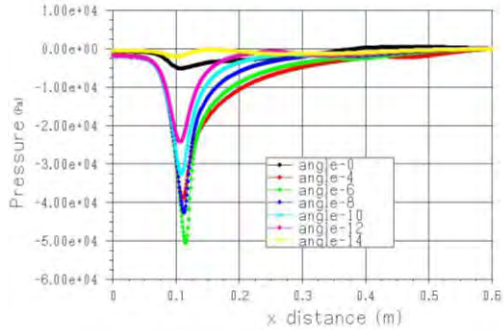
4.3. Effect of the Diffuser Angle “θ”

Fig.7 shows the calculation results when d=0.5 mm, r=20 mm, and taking the degree of the diffuser angle as 0°, 4°, 6°, 8°, 10°, 12°, 14°, respectively.

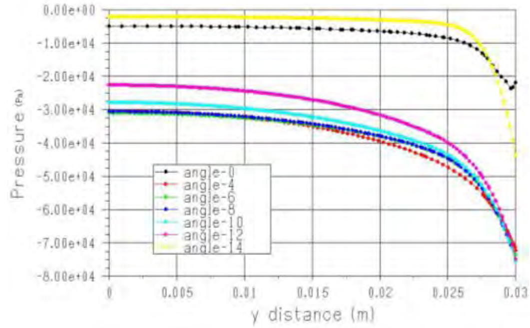
It can be seen from Fig.7 (a) that the diffuser angle has great influence on the pressure distribution inside the annular foam breaker. The magnitude of the pressure near the throat decreases with an increase of the value θ until θ=6°, then it begins to increase with increasing θ value. When the value θ increases to 14°, the pressure inside the foam breaker is almost back to ambient pressure. Similar results are obtained for the pressure profile at the throat plane as shown in Fig.7 (b). Therefore, the optimum value of the diffuser angle θ is 6°.

4.4. Effect of the Diffuser Length-Radius Ratio “α”

Keeping the annular slot width as 0.5mm, the Coanda surface radius as 20mm and the diffuser angle as 6°, the effect of the diffuser length-radius ratio on the pressure distribution has been studied by varying the value α as given in Fig.8. The larger of the diffuser length-radius ratio α is, the lower of the valley value of the static pressure at the center axis is, and the position of the valley value moves to the downward direction of the axis.

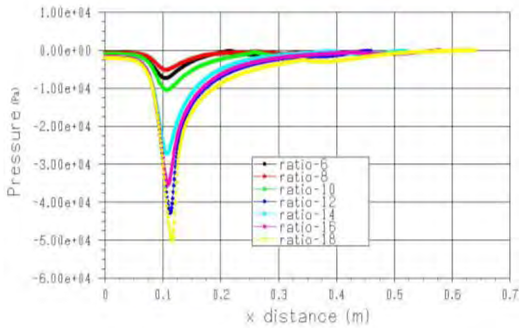


(a)

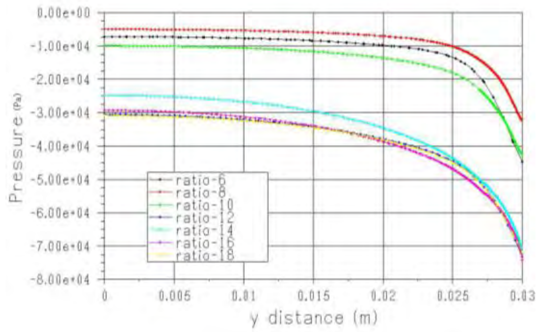


(b)

Figure 7. Static pressure profiles for various “θ”: (a) Static pressure profiles along the axis (y=0), (b) Static pressure profiles at the throat section.



(a)



(b)

Figure 8. Static pressure profiles for various “α”: (a) Static pressure profiles along the axis (y=0), (b) Static pressure profiles at the throat section.

Fig.8 (b) shows the static pressure at the throat plane decreases gradually with an increase of the values α. When the values α is more than 14, the magnitude of the pressure along the throat plane changes a little. In order to provide the convenience for manufacturing process, the value α advised here is 15.

5. EXPERIMENT

Based on the above simulation results, an optimum structure of the annular foam breaker, named the type-2 foam breaker, is designed and tested in the well bore flow simulation loop experimental stand, which is specially designed to characterize the rheological behavior, carry capacity and the foam-breaking ability of foams and aerated fluids at different conditions of quality, pressure, temperatures and injection of contaminants, as shown in Fig. 9. The foaming fluid used in experiment is same with the one used in the field, which is the polymer-surfactant-based aqueous solution. The surfactant used to generate the foam is Sodium Dodecyl Sulfonate (SDS) at concentrations of 0.3～0.5 wt% in distilled water. Xantan Gum (0.05%～0.15 wt%) and aqueous polymer solution of Anion Polyacrylamide (0.02～0.07 wt%) are used as the viscosity increase agent and foam stabilizer, respectively. The half-life of the foam system is about 30-90 min, which is relevant to the concentration of the foam stabilizer. The air flow rate to drive the foam breaker is 2 m3·min-1 and the operation pressure is about 0.6MPa.

The experimental results recorded at intervals of 30s are given in Table 1. For both the type-1 and the type-2 foam breaker, the lower of the gas to liquid ratio is, the higher of the foam-breaking efficiency is. So, it is more effective in destroying wet foam system for the annular foam breaker. When the ratio of gas to liquid decrease to 50, the type-2, optimized annular foam breaker, increases the foam-breaking efficiency from 71.16% to 86.58% compared with the type-1. The foam-breaking efficiency is improved by some 22.61%.

It can be seen from Fig.10 that the foam system has a large volume before foam-breaking occupying a vast space. When the annular foam breaker is operating, the foam volume reduces to such an extent that the fluid mixture outflow from the foam breaker can be pumped easily. Therefore, the liquid extracted from the degraded foam can be reutilized in timely, which will significantly reduce the cost of the foam drilling.

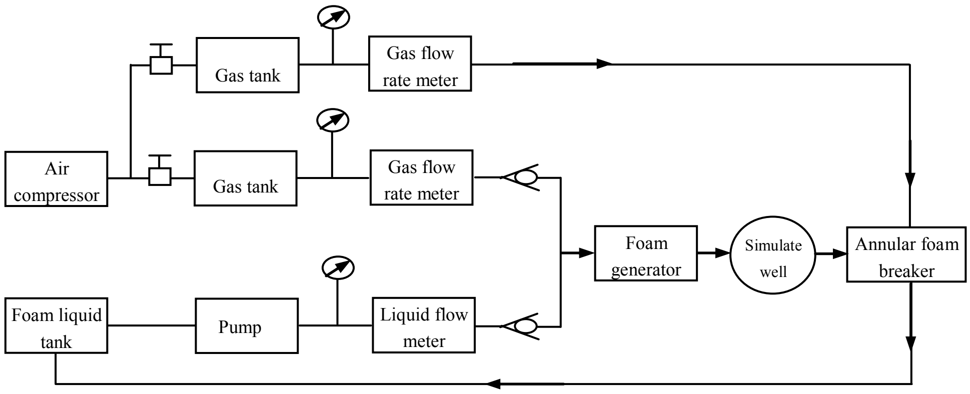


Figure 9. Sketch of well bore flow simulation loop experimental stand.

TABLE 1. Foam-breaking results obtained in experiment (30s)

Variables		Gas to liquid ratio of foam system				
		300	150	100	75	50
Liquid flow rate (L/min)		0.2	0.4	0.6	0.8	1.0
Foam volumes before breaking V_1 (L)		19.6	36	46.7	52.3	56.1
Type-1 foam breaker	Foam volumes after breaking V_2 (L)	7.05	12.11	14.51	15.85	16.18
	Foam-breaking efficiency η (%)	64.03	66.36	68.93	69.69	71.16
Type-2 foam breaker	Foam volumes after breaking V_2 (L)	4.75	8.16	6.20	6.67	7.53.
	Foam-breaking efficiency η (%)	75.76	77.33	86.72	87.25	86.58

(a) (b)

Figure 10. Experimental pictures of the type-2 foam breaker: (a) The state of the foam fluid before breaking, (b) The state of the foam fluid after breaking.

6. CONCLUSIONS

A computational study has been performed to investigate the flow characteristics inside the annular foam breaker. The effect of various geometric parameters on the pressure distribution inside the annular foam breaker has been examined. Based on the results obtained in the present work, the following conclusions can be drawn:

1. The annular foam breaker is one which uses the Coanda Effect to break foam. A stream of air at high velocity attached to a curved surface causes a low pressure region nearby, which results in foam-breaking. So, the negative pressure distribution has a strong influence on the performance of the annular foam breaker.
2. The numerical results indicated that the pressure is lowest when the width of the annular slot d=0.5mm, the Coanda surface radius r=20mm, the diffuser angle θ=6°, and the diffuser length-radius ratio α is more than 14. They are the optimum parameters for the annular foam breaker discussed in this paper.
3. From the experimental results, it can be concluded that the annular foam breaker is more effective in destroying wet foam system. Compared with the old ones, the foam-breaking efficiency of the optimized annular foam breaker is improved from 71.16% to 86.58%, which increases by some 22.61%.

It is preferable to use an annular foam breaker based on Coanda effect to break foam drilling fluid. However further studies such as using wider operating conditions and comparing with the experimental results should be performed in the near future.

7. ACKNOWLEDGEMENT

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چکیده

کف شکن حلقوی وسیله‌ای است که از نیروی برشی و خلاء ایجاد شده توسط اثر کواندا برای شکستن کف استفاده می‌نماید. توزیع فشار به طور مستقیم بر عملکرد آن تاثیر میگذارد. در نتیجه بررسی ویژگی‌های جریان در داخل کف شکن حلقوی به منظور بهینه سازی ساختار آن است مهم است. در این مقاله، از کد دینامیک سیالات محاسباتی (CFD)، FLUENT، برای شبیه سازی پدیده های جریان استفاده شده است. اثر پارامترهای مختلف هندسی بر روی توزیع فشار در داخل کف شکن حلقوی، از جمله عرض شکاف حلقوی، شعاع سطح کواندا و ابعاد منتشرکننده، و غیره مورد ارزیابی قرار گرفته است.نتایج عددی نشان می دهد که مقدار بهینه عرض شکاف حلقوی $d = 0.5mm$، شعاع سطح کواندا $r = 20mm$ ، زاویه منتشرکننده $\theta=6°$ و نسبت طول منتشرکننده به شعاع بیش از ١٤ است. بر اساس این تحلیل‌ها، ساختار بهینه کف شکن حلقوی طراحی شده و در شبیه سازی جریان مته چاه با تجهیزات آزمایشگاهی مورد مطالعه قرار گرفت. در مقایسه با نمونه‌های قدیمی، بازده شکستن کف در این کف شکن حلقوی بهینه سازی شده از ٧١/١٦٪ به ٨٦/٥٨٪، بهبود یافته است و در برخی موارد تا ٢٢/٦١٪ افزایش یافته است.

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