Technological capabilities of direct-flow stabilizers in gas-piston engines

K A Bashmur[1], E A Petrovsky[1], Yu A Geraschenko[1], V A Makolov[1],
V S Tynchenko[1] and Yu N Shadchina[1]

[1]Siberian Federal University, 79, Svobodny Avenue, Krasnoyarsk, 660041, Russia

E-mail: bashmur@bk.ru

Abstract. The present study describes problems related to the rational use of associated petroleum gas. In particular, the problem of effective gas flow stabilization at the gas-piston engine outlet is investigated. The analysis is applied to such kind of engine stabilizers and detailed studies revealed their major drawbacks. A hypothesis concerning the efficiency of using a direct-flow stabilizer (turbulizer/swirler) as a flow stabilizer is proposed. Simulation flow modeling in the direct-flow stabilizer is carried out. The simulation is carried out with the help of the SolidWorks Flow Simulation program for different profiles of the stabilizer flow section. The hypothesis on the efficient use of such units is confirmed. In terms of flow swirling the most effective flow section of the direct-flow stabilizer is revealed.

1. Introduction

In many cases petroleum gas (APG) is burned on flaring units or dissipated into the atmosphere at the oil and gas fields. According to miscellaneous data from 60 to 100 Bcm (billion cubic metres) of APG is burned on flaring units or dissipated into the atmosphere annually in the world. The loss of such valuable energy raw material is highly unpractical. In addition emission of associated petroleum gas causes serious environmental problems. Therefore, the rational use of APG is one of the main problems of oil and gas industry [1].

In general there are various methods of APG utilization and processing such as APG injection into geological formations in order to increase the well flow rate; producing heat and electric power; refining and petrochemical production in order to extract various useful components, etc. [2]. It should be noted that in the first two cases when using APG at the oil and gas fields the gas-piston and gas-turbine engines are used. In the main the paper is primarily concerned with the problems of effective gas flow transformation in the gas-piston and gas-turbine engines.

2. Gas-piston and gas-turbine engines power units are used at the oil and gas fields

Currently the oil and gas industry is increasingly using gas-piston (GPE) and gas-turbine (GTE) engines [3, 4]. APG is used as fuel for these units. They are used mainly to generate electricity and maintain the reservoir energy [5].

Hot gases flow is formed by combustion of gas-air mixture in both engines. The mixing of the flow is carried out on the mixers-stabilizers taking into account the Venturi effect in the narrowing units [6]. Thus swirling gas flow is formed.

The flow swirling in gas-piston (GPE) and gas-turbine (GTE) engines is accomplished to stabilize combustion processes, intensify gas and fuel mixing and control temperature and poisonous gases emissions into the atmosphere [7].

The main problem of these mixers is that they do not allow regulating the flow swirling since the swirling is significantly reduced at low operating conditions (i.e. low Reynolds number) and the efficiency of such swirlers falls [8].

In this connection, it is worth noting that literature points [9] to the fact that heat-exchange intensification is possible due to additional swirling of the flow and the effect of heat-exchange area increasing due to heat transfer surface ribbing or surface profiling.

3. Types of swirlers. Application of direct-flow stabilizer

It is obvious, that it is possible to regulate the swirl of flow by means of a swirler. Currently, there are many designs of swirlers: twisted tapes, augers, tangential flow swirlers, axial-vane-type swirlers, etc.

There exist some swirlers which partially overlap the passage section. These include, in particular, screw ribbing swirlers, wire winding swirlers, and also corkscrew winding swirlers called also direct-flow ones [10].

The direct-flow swirlers that partially overlap the passage section are considered to be the most promising for use [11]. Unlike other types of swirlers they can be effectively applied in multi-phase flows providing the global swirling of fluid flow due to the curvature of streamlined surfaces and presence of flow separation zones.

A flow swirl (created by the direct-flow swirlers) i.e. directional additional convective transfer of impulse, mass and energy in the tangential direction can positively influence on the thermal energy efficiency increasing and the operating reliability.

In terms of profiles shape the direct-flow swirlers (Figure 1) can be classified into triangular, trapezoidal, semicircular, sinusoidal and rectangular ones. The profile shape has a determining effect on the formation of flow separation zones and flow connection zones, the structure of recirculation areas and the turbulent transfer in the mixing layer.

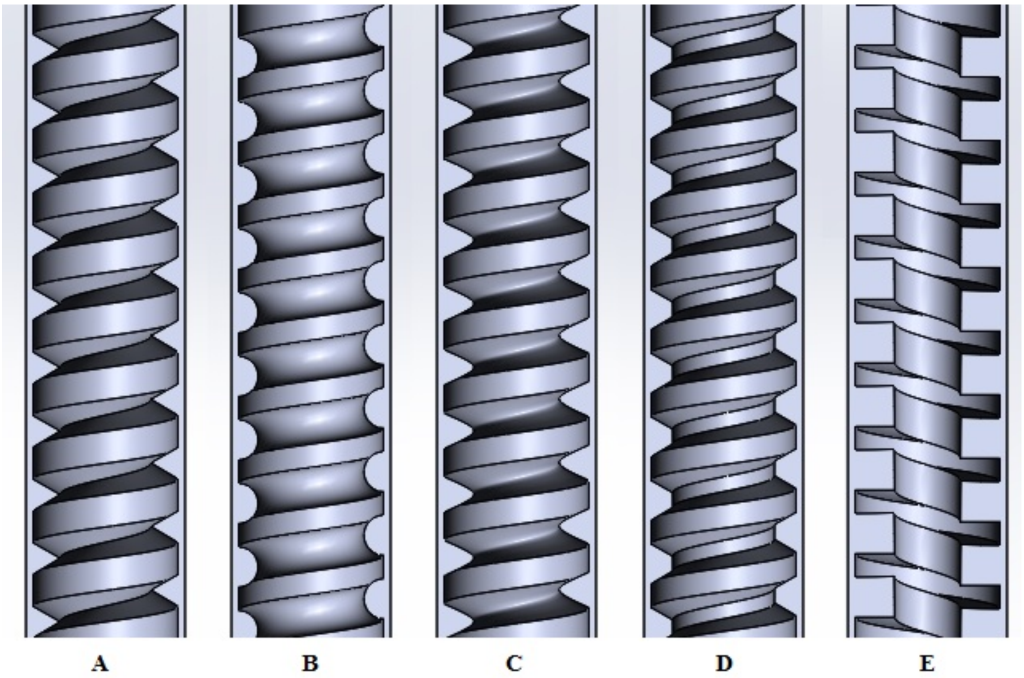

Figure 1. Swirler profiles: A – triangular; B – semicircular; C – sinusoidal; D – trapezoidal; E – rectangular

4. Simulation of the direct-flow stabilizer is presented

The purpose of gas flow simulation was not only a possible estimation of direct-flow stabilizers application in gas-piston (GPE) and gas-turbine (GTE) engines but the influence of flow-section profiles (Figure 1) on the efficiency of flow swirl.

SolidWorks Flow Simulation software was used to simulate flow swirling. This program was selected due to a convenient interface, an ability to build dependency graphs for different characteristics of the flow. One more thing is the possibility of operating with multi-phase flows. In particular, a mixture of the following gases - methane, ethane, butane, and nitrogen oxides NO_x was taken as a flow of APG.

The initial data for gas flow simulation through the direct-flow stabilizer are presented in table 1.

Table 1. Data are used for simulation

1.1. Stabilizer length, m	1.2. 1.5
1.3. Stabilizer external diameter, m	1.4. 0.200
1.5. Stabilizer inner diameter, m	1.6. 0.182
1.7. Turning number	1.8. 10
1.9. Flow velocity, m/s	1.10. 300
1.11. Total pressure, MPa	1.12. 5

5. Simulation results

The hydrodynamic simulation conducted in accordance with SolidWorks Flow Simulation allowed getting the influence of the swirler profile on the flow swirl (Figure 2).

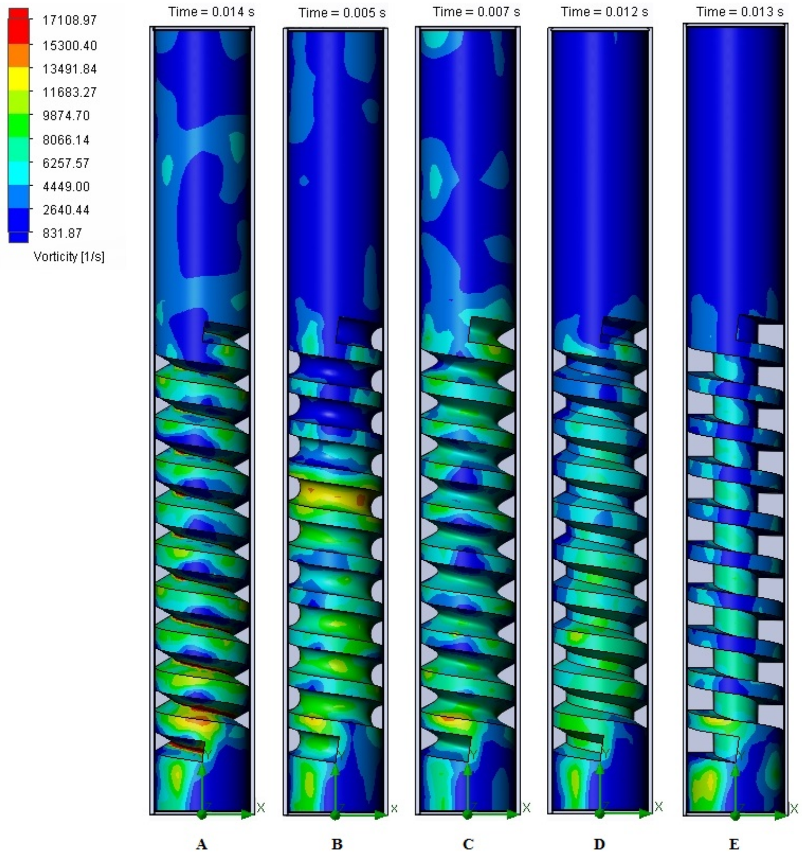

Figure 2. Simulation results of the flow swirling in the stabilizer. Swirler profiles: A – triangular; B – semicircular; C – sinusoidal; D – trapezoidal; E – rectangular

The following maximum parameters of the profiles swirling: triangular – 34000 1/s; trapezoidal – 9600 1/s; semicircular – 13100 1/s; sinusoidal – 13800 1/s; rectangular – 15200, 1/S have been obtained.

Thus, the triangular profile stabilizer has the maximum value of the flow swirling indicators. The swirling graph of the triangular profile direct-flow stabilizer depending on the gas trajectory length on its coils is presented in Figure 3.

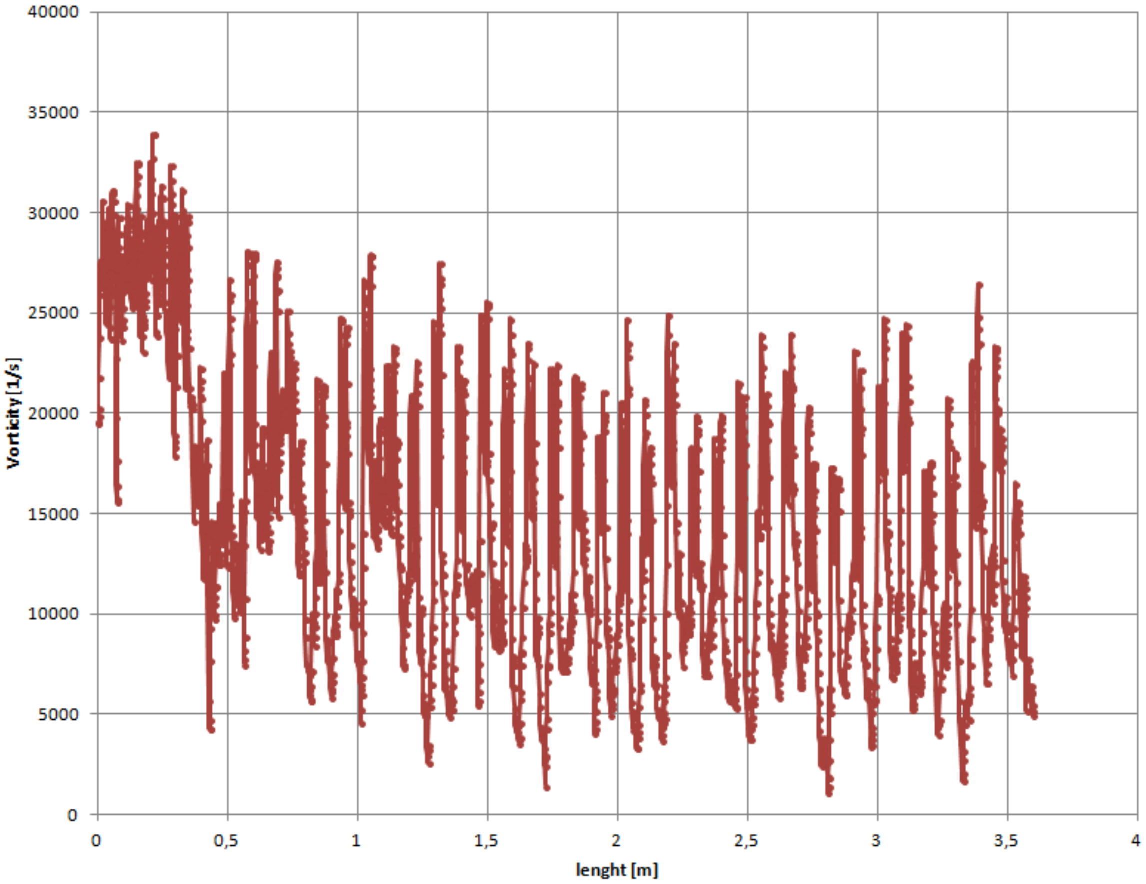

Figure 3. Swirling graph of the triangular profile direct-flow stabilizer depending on the gas trajectory length on its coils

These indicators of swirling are almost comparable to the indices of diffusers [12]. There was a picture of additional local swirling formation in the triangular profile stabilizer coils. This feature distinguishes it from the other stabilizer profiles.

The rectangular profile stabilizer is much less effective. The swirling indicators of the sinusoidal and semicircular profile stabilizers are approximately the same, but the swirling is significantly reduced on the last 3 turnings. The least effective one is the trapezoid profile stabilizer.

6. Discussion

The parameters of the APG flow swirling in the direct-flow stabilizer practically do not concede to the traditionally used diffusers. In this case, the direct-flow stabilizers are structurally easier to make adaptable to the flow parameters, for example, changing the angle of inclination of the profile, turning number, etc. Thus, further researches of the direct-flow stabilizers are relevant, in particular, determination of their optimal parameters depending on the gas flow properties and corresponding control automation of such system. The design and study of the hybrid stabilizer system using an applied relief diffuser is of great interest.

7. Conclusion

Different cross section profiles devices were obtained in the SolidWorks software complex. Using the gas flow simulation in Flow Simulation Module the authors of the article confirmed the hypothesis that the direct-flow stabilizers (swirlers) can be effectively used to stabilize the flow in gas engines since the flow swirling parameters are practically the same as traditionally used diffusers.

Various cross section profiles of the direct-flow stabilizers were analyzed as well. It was revealed that it was advisable to use the triangular profile stabilizer for better flow mixing as it possessed the best turbulence indicators.

References

[1] Vanadzina E, Gore O and Viljainen S 2015 Electricity production as an effective solution for associated petroleum gas utilization in the reformed Russian electricity market *Lab. Electricity Market and Power Systems Lappeenranta University of Technology Lappeenranta, Finland*

[2] Filippov A, Vartumyan G and Tkachenko L 2009 Associated gas – Passer or valuable resource? *Oil, gas and business* [in Russian – Neft, gaz i bizness] **12** 29–31

[3] Hinderaker L and Njaa S 2010 Utilization of Associated Petroleum Gas *SPE Russian Oil & Gas Techn. Conf. and Exhibition held in Moscow* p 12

[4] Bokovikova T and Savitskii S 2011 Development and study of vortex apparatus for preparing associated petroleum gas for transport *Chemical and Petroleum Engineering* **47** 545–9

[5] Verbitsky V, Igrevsky L, Fedorov A, Goridko K and Gubkin A 2016 Technology Design of Efficient Utilization of Associated Petroleum Gas APG and Possibilities of Its Realization by Pump-Booster and Pump-Ejector Systems *SPE Russian Petroleum Techn. Conf. and Exhibition Moscow* p 17

[6] Gol'diner A, Tcyrkin M and Bondarenko V 2006 *Gas piston electrical units* (St. Petersburg: Galleya Print)

[7] Lee C and Moon C 2002 An experimental investigation of the effects of turbulence generators attached to an axial swirler nozzle on mixing and combustion *Aerospace Science and Technology* **6(7)** 517–20

[8] Yehia E, Saqr K, Aly H and Jaafar M 2009 CFD insight of the flow dynamics in a novel swirler for gas turbine combustors *Int. Communications in Heat and Mass Transfer* **36(9)** 936–41

[9] Webb R 1994 *Principles of Enhanced Heat Transfer* (New York: John Wiley & Sons)

[10] Mitrofanova O 2010 *Hydrodynamics and Heat Transfer of Swirling Flows in Channels of Nuclear Power Facilities* (Moscow: Fizmatlit)

[11] Bergles F 1996 The Encouragement and Accommodation of High Heat Fluxes *Proc. 2nd European Thermal-Sciences and 14th UIT National Heat Transfer Conf.* (Rome, Italy) pp 3–11

[12] Karuppusamy P and Dr. Senthil 2013 Design, Analysis of flow Characteristics of Catalytic Converter and effects of Backpressure on Engine Performance *Int. J. of Research in Engineering & Advanced Technology* **1** 6