DOI 10.2478/ntpe-2019-0031

2019
Volume 2
Issue 1
pp. 295-303

The use of simulation modeling in the design of elements of annular preventers

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Date of submission to the Editor: 05/2019
Date of acceptance by the Editor: 07/2019

INTRODUCTION

The blowout equipment, including annular preventers, is one of the main control elements over any wells in the process of their constructions. Such equipment has an effect on the wells that provides coal veins degassing to reduce gas-dynamic activity (Ilyashov et al., 2013, Pavlov, 2011). Modern technology of the working process reshapes it and requires the expansion of the annular preventer sealing unit functioning with the simultaneous provision of its operational characteristics.

Taking into the consideration the fact that the sealant operates in a closed body and there is no access to it during functioning, the question, concerning the control over its technical condition during the annular preventer running, as well as the predicting its resource and the developing of relevant criteria for evaluation of its technical condition, remains as an actual one.

At present, certain theoretical and experimental investigations about the annular preventer design and operating are known. The paper (Shpeht, 2005) looks at the scientific-methodical basis of the analysis, the efficiency estimation and durability of the seal components of ram and annular preventers according to the operational tests results of the blowout equipment, including qualitative data of the sealing components material. This integrated approach allows us to apply calculations methods both for assessing the situation and for choosing measures to prevent and eliminate all the risks relating to the gas and oil exploration.

Nevertheless, these investigations results are insufficient to provide a systematic approach to the implementation, planning and development of sturdy design of either annular preventers or their sealants (Mosora et al., 2018). Firstly, there is no scientifically substantiate methodology of determining geometric and power parameters of both the annular preventer and the sealant which would provid the sealing ability of the preventers in all standard sizes. The

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effect of sealing armature geometry on the stress-strain state of a rubber sealant has not been studied yet.

The simulation modelling is one of an accelerated analysis tools that improves speed of engineering problem solving that is nonanalytic and takes considerable time (Dzhuset al., 2014, Dzhus, 2015, Dorokhov and Kostryba, 2016). The progress in numerical methods gives an opportunity to expand a range of analysis issues. The results obtained via these methods are being used by almost all branches of science and technology. The finite element method deserves particular attention.

A technique of manufacturing and designing a blowout seal has been suggested for the annular preventers according to the using of the finite element method(Shafiq, 2008). The seal includes a rigid material insert disposed within an elastomeric body.

The method of manufacturing, certification and optimization for sealants of the preventers is also mentioned. This method includes generating a seal model into the finite element modelling, smoothing a sealant, and analysis of its deformed area, taking into account the movement conditions (Shafiq, 2008).

The stress-stain state of the rubber seal of the cuff type packers is investigated by means of simulation modelling (Grebenyuk et al., 2014). Such packers are considered to be self-compacting, are used to check seal capacity of oil and gas wells, and start working under pressure in a well. Using a space-time finite element helps to solve problems in the software complex “MIRELA+”. As a result of this research, the displacement distributions, deformations and strain of a rubber element as a consequence of viscoelastic deformation have been obtained. The size of the cuff precipitate in agreement with the load and rheological characteristics of a material has been also defined.

The same authors (Vasko et al., 2015) propose a finite element approach for solving a three-dimension problem by the investigation of the stress-strain state of the rubber seals of the cuff type packers. The approach is to sequentially solve a series of linear problems, listing at each step the matrix of rigidity of the whole structure. A numerical solution for solving the problem of an elastomeric cuff deformation in a three-dimensional formulation has been depicted. As a result, the components of the stress-strain state of the rubber seals of the cuff type packers have been obtained within the large deformations that arise in the process of the verification of the sealing capability in oil and gas wells.

The widespread use of the finite element method is a confirmation of its perfection and its possibility to be used as means of studying the behavior of the structures under load. The main condition for obtaining suitable and accurate results is the correct choice of the behavioral model of the construction material, in other words, a physical model of deformation with appropriate physical parameters.

In order to ensure the high reliability of the simulation modelling results within the investigation of the seals stress-strain state as well as their optimization, there is the necessity of a detailed experimental study of this process and of a contrastive analysis of this one with the corresponding simulation modelling.

Their coincidence will create the possibility for the research via mentioned simulation modelling.

METHODOLOGY OF RESEARCH

Nowadays there are a lot of software products based on the finite element method. In accordance with the purpose and the scope of application they are connected with a wide range of element types and different material behavior. Therefore, the first and a very responsible step for the correct finite element model construction is a choice of material behavior model. A number of physical properties corresponding to a chosen model should be determined.

The physical characteristics and the correlation between the deformation and strain of the materials, which the seals are made of, are regarded as hyperplastic models. On the deformation the behavior of rubber resembles a viscous liquid. At the same time, it is practically an insoluble material. Schematic diagram depicts a nonlinear stretching and one or two inflection points (Fig. 1).

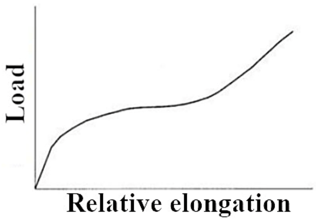


Fig. 1 The nature of the dependence «load/relativeelongation» ofhyperelastic materials

The finite element modelling and calculating techniques for rubber and some polymeric materials based on several material behavior models such as: Arruda-Boyce, Blatz-Ko model, and Mooney-Rivlin one that are used to describe the behavior of low-density rubber within compressive strength and is formed on the dependence upon a strain energy density function. It may combine about nine parameters of the strain tensor deformation invariants. The value of these constants are usually determined by the analytic description of the experimental data. Modern software products demonstrate a great possibility to calculate the required parameters by experimental data processing and to obtain graphic source information interpretation.

As the preventer seal is usually made of low-density rubber so the Mooney-Rivlin model may be used to represents material behavior. The Mooney-Rivlin models exist with 2.5 and 9 parameters. These constants characterize material's properties and are determined by the "strain/deformation" dependencies under different conditions. To determine constants of energy changes it is necessary to experimentally determine the "load/relative elongation" dependence.

A series of experimental studies are required to be conducted with specially designed samples. To ensure the high simulation reliability of the sealing performance it is necessary to reconcile its results with the experiment ones. In our case, studying of material properties and checking of simulation modelling results are combined with the aim of reducing the cost of conducting experimental research. There were carried out some experimental research of custom models that include design peculiarities of annular preventer sealant. The simulation modelling provides the determination of the Mooney-Rivlin model with two constants and their application during the design and investigation of preventer seals.

The research was carried out on the rubber-metal models in the form of sectors. The model under investigation is somewhat simplified with comparing to current models. Anyway, it meets all the requirements to the standard loading process of the sealant in the places which could be easily destroyed. The model dimensions have been defined by geometric modelling (Scale 1:2) of the preventer sealant PU1 350 x 35. Several models have been obtained in a specially designed mold by vulcanization.

Rubber's physical and mechanical properties required for the model production corresponded to the ones of the real sealant. Similar requirements have been observed within technological modelling.

Fig. 2 Experimental model

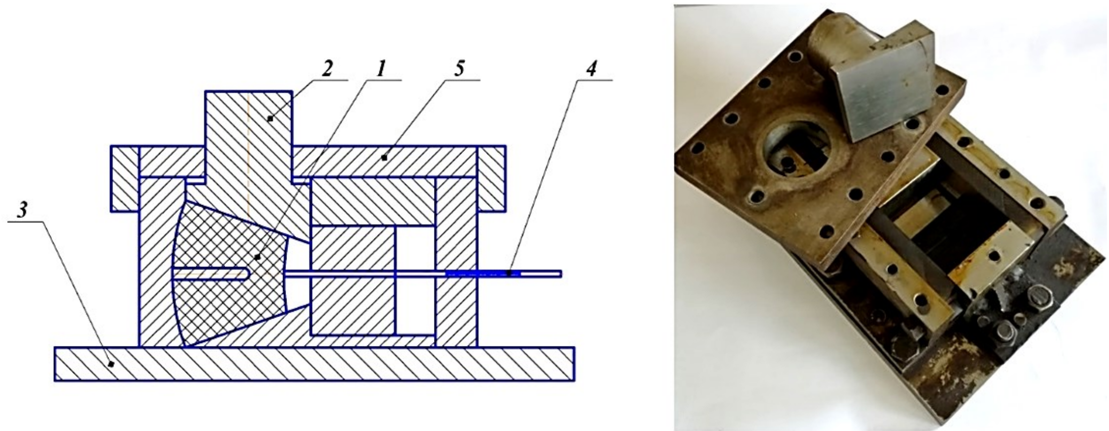
The rubber models in the shape of segments in 78 mm height are reinforced with a single metal insert. Separate segments differed in insert sizes (thickness and width).

Laboratory tests were carried out at the experimental installation that included three hydraulic cylinders, a load testing prefix, hydraulic control system, a system of measurement and of load parameters control (Fig. 3).

Fig. 3 Test installation

The side cover hydraulic cylinder of a tap preventer mounted on four rack units was used to create the load. The hydraulic cylinder diameter was 200 mm. The axial force at a pressure of 10 MPa was 300 kN. The stroke of the hydraulic cylinder was 150 mm.

The prefix design provided the deformation of the model (1, Fig. 4) under the plunger (2, Fig. 4) action in the radial direction while the sealant was operating. The prefix side walls lined with glass ones were used to reduce the friction force within the model deformation, visual observation of the loading process and the state of the model under test. Longitudinal slots were foreseen to monitor the side walls.



a b

Fig. 4 Prefix scheme

The axial force on the test model was measured and controlled with the help of a strain gage mounted in the power cylinder rod. The degree of the model loading was determined by the magnitude of its radial deformation at the signifier (4, Fig. 4).

The software representation was based on the model study results obtained in the contact conditions with the counter body by which the sealed tube was imitated. For a model with an insertion width of 50 mm and a thickness of 7 mm, that deformation was obtained at a load of 80 kN.

RESULTS OF RESEARCH

The prefix model with geometric parameters was constructed to represent the simulation modelling of loading process (Fig. 5). The sealant model (2, Fig. 5) with the insert (3, Fig. 5) of the same parameters was reproduced.

The next step was the solution of an inverse problem. It reproduced the experimental results and the determination of two constants for the Mooney-Rivlin model.

The load was applied to the plate (1, Fig. 5) equal to 80 kN. There was also a limit on the rubber element movement along the X axis which corresponded to the sealant displacement in the radial direction.

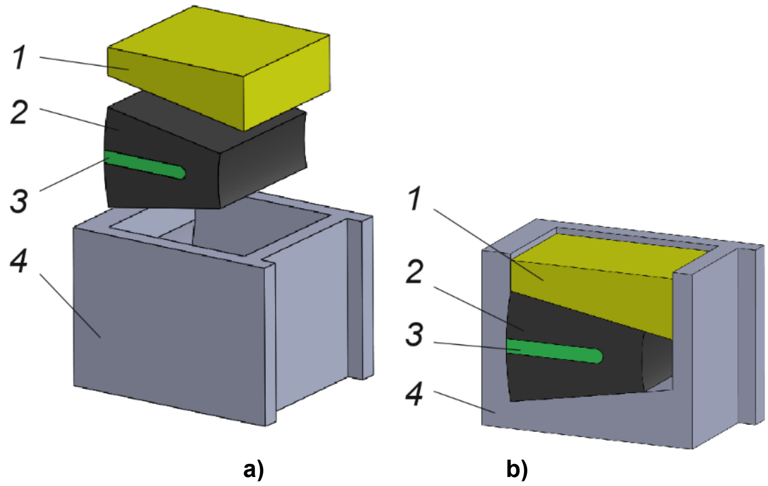


Fig. 5 The prefix model with the sealant element for simulation modeling:
1 – plate; 2 – rubber element; 3 – metal insert; 4 – case
a) – diversity; b) – fold-form

The simulated model was designed to conform to the modelling objectives by executing some iterations. Namely, a maximum displacement of 15,73 mm was obtained at the load as mentioned above (Fig. 6).

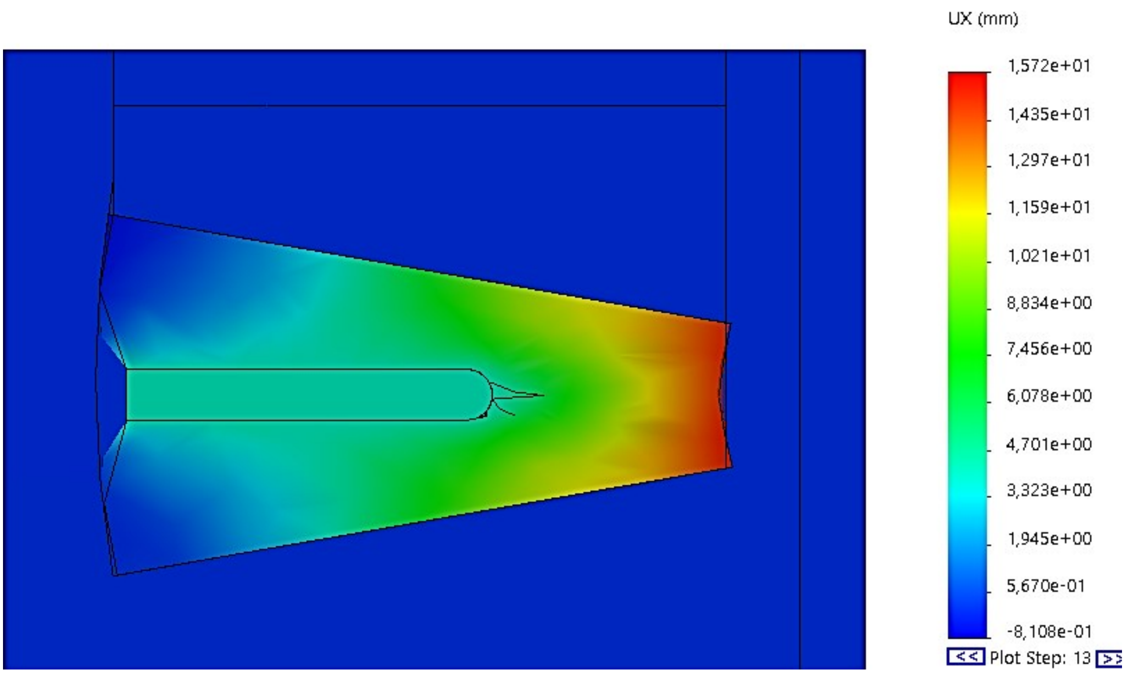


Fig. 6 Rubber sheet moving in terms of its maximum

The method used is the Trial and Error one that provides sequential cyclic changes in the material constants. As a result, a model which meets the requirements of the accuracy and adequacy is received. Thus, the first constant value is 1,8 MPa and the second – 0,6 MPa (Fig. 7).

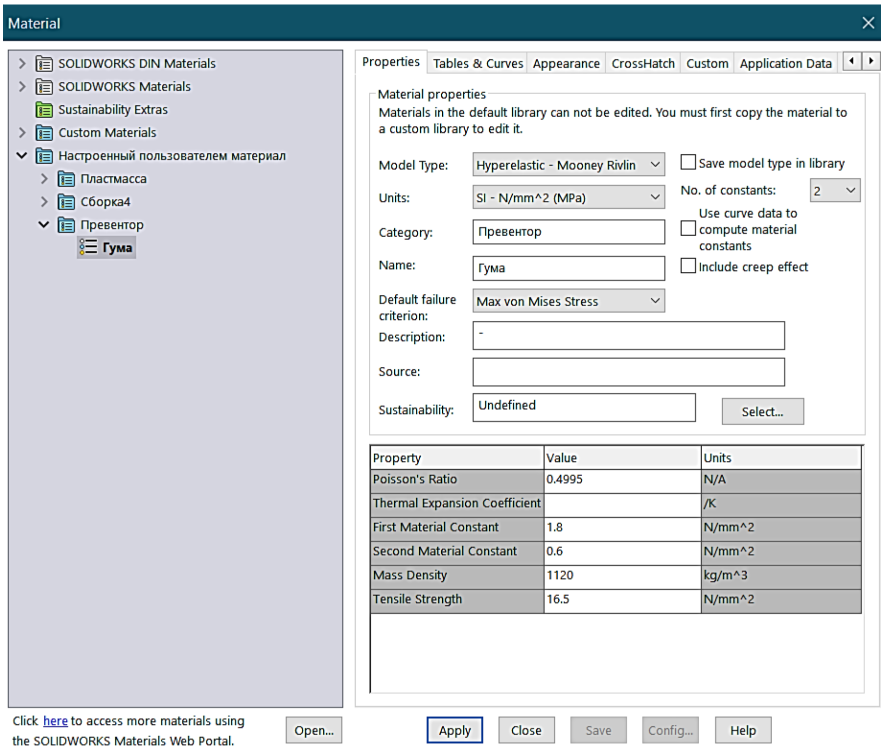


Fig. 7 Program window with defined constants

DISCUSSION

In the course of experiments, it has been determined the load value of the process when the models with the inserts 30 and 40 mm in width were undergone a deformation. They were respectively 59 and 66 kN. The obtained results helped to check the proposed method reliability within the determination of the material constants to realize the Mooney-Rivlin model.

The investigation issues according to the stress-strain state were obtained after changing the insert width in the parametric model constructed for simulation modelling and after using the established constants value. The results for the model with an insert 40 mm in width at a load of 66 kN are shown in Figure 8.

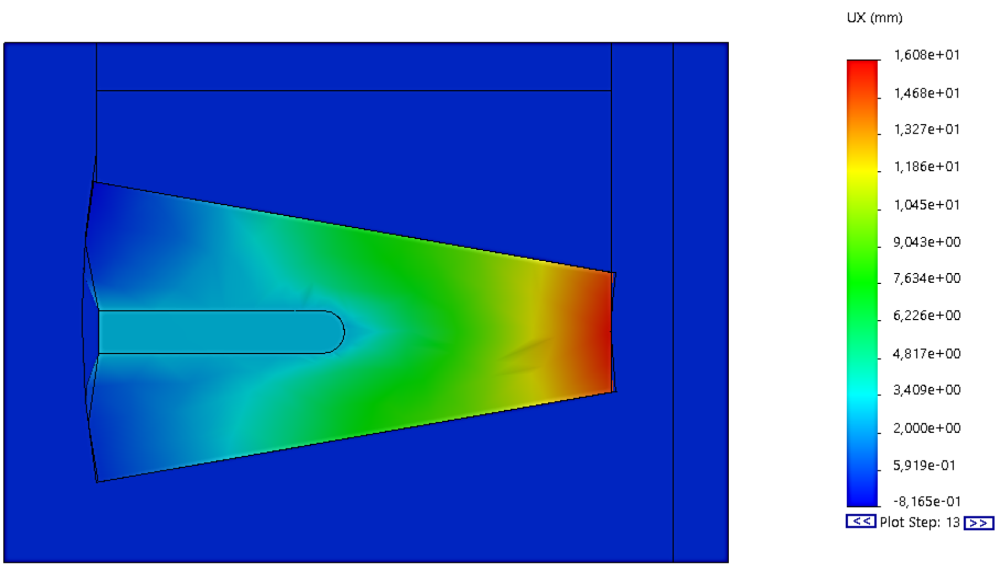


Fig. 8 Rubber sheet moving with an insert 40 mm in width at a load of 66 kN

The results for the model with an insert 30 mm in width at a load of 59 kN are shown in Figure 9.

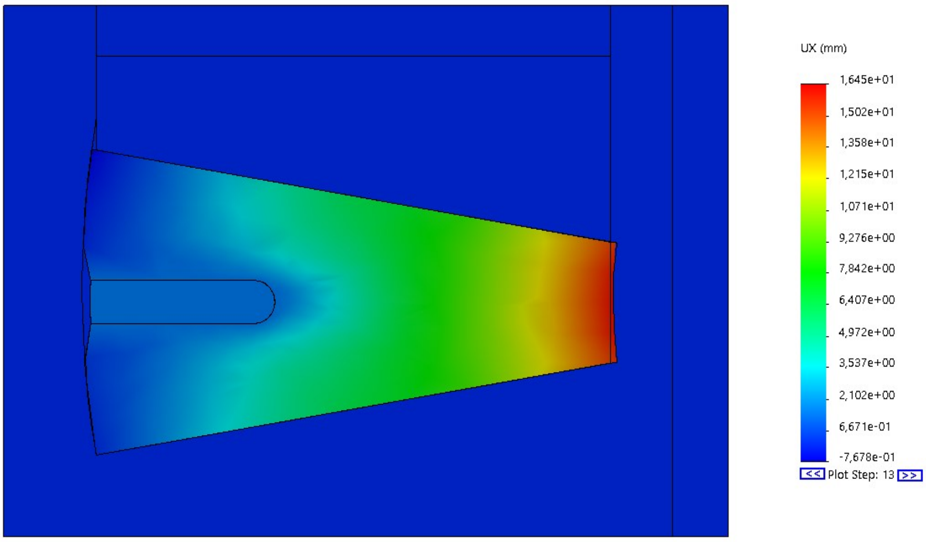


Fig. 9 Rubber sheet moving with an insert 30 mm in width at a load of 59 kN

Comparing the obtained results shown in Figures 6, 8, and 9, especially the values of maximum displacement of 15.73 mm, 16.08 mm and 16.45 mm, it may be concluded that they are sufficiently reliable. The error is 5%. In this cace, it includes the errors of simulation and experimental research.

CONCLUSION

The theoretical and experimental studies provided the determination of the material constants to implement the Mooney-Rivlin model that was used to describe the behavior of low-density rubber in software product based on the finite element method. The method of determining the sealant material constants has been tested on the experimental results of its simplified model. The aggregation error is 5%. The possibility of using simulation modelling in the annular preventers design situations and within the study of the armature geometry influence of the sealant fittings on its stress-strain state have been confirmed by a high reliability of obtained results.

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Abstract.

One of the main elements of control over wells in the process of their construction is the blowout equipment, which includes annular preventers. This also applies to wells that provide degassing of coal veins to reduce their gas dynamic activity. Modern technology of work requires expansion of the functionality of the sealing unit of the annular preventers with the simultaneous provision of its operational characteristics. Determining the necessary durability of seals for different operating modes is the study of their stress-strain state. The paper deals with the possibility of using simulation modeling in the annular preventers design situations and within the study of the armature geometry influence of the sealant fittings on its stress-strain state. The method of determining the material constants to realize the Mooney-Rivlin model has been proposed. The behavior of low-density rubber in software product has been described by the finite element method. The aggregation error of experimental and theoretical studies is 5%. Therefore, the preconditions and the possibility of using simulation modeling in the design of annular preventers devices with increased operational characteristics have been created and confirmed.

Keywords: simulation modelling, stress-strain state, annular preventer