

THE SPECIAL FEATURES OF USING FRACTURE ARRESTORS IN NATURAL GAS TRANSMISSION PIPELINES

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Abstract: This paper presents the features of using fracture arrestors in order to increase the safety of gas transmission pipelines operation. The paper presents the main causes of operating failure, fracture behavior, the anticipated failure methodology, the criteria for determining the usage necessity and the lay-out of the fracture arrestors for this important category of pipelines.

Keywords: pipelines, fracture behavior, fracture arrestor, Battelle two curve method

1. THE PIPELINES FAILURE AND THE FUNCTION OF FRACTURE ARRESTORS

The lack of material due to corrosion and fracture flat flaws cause the most frequent technical failures to gas transmission pipelines and the failure/burst processes are initiated in sections with pipeline tubing flaws. As gas transported through pipelines is compressible, the failure (burst), accidentally started in an area with pipeline tubing flaws and which generates the loss of its impermeability, grows as long as it is supported by the energy released during the transitory process of gas pressure dropping. The fracture grows on a bigger or smaller length, based on the toughness of the material (steel), of the pipelines, which determines the necessary energy level for fracture growth initiated in a flawed area. As regards the trunks made of high resistance steel pipes (X60, X70, X80, X100 or, more recently X120 which has the yield strength $SMYS \geq 840$ MPa), long distance fracture growth may be produced, as the ones presented in figure 1, where D_e – the pipeline outer diameter, s – pipeline wall thickness, MP – the steel the pipeline is made of, $SMYS$ – the specified minimum yield strength of MP , GP – the gas transported through the pipeline, p_b – pipeline burst pressure, σ_{hb} – the hoop stress in the pipeline corresponding to p_b pressure [1,2,4,8-11].

Many cases of operating pipeline failure assessment or pressure sampling assessment led to the establishment of the data summarized in table 1 concerning the features of pipelines fracture behavior [5-7].

The need to increase the safety of operation of gas transmission pipelines led to the idea of mounting some fracture arrestors on them, located in areas subject to failure initiation and which have the capacity to absorb much deformation energy and which can thus consume a great part of the available energy for fracture growth [8,9,12].

2. THE SPECIAL FEATURES OF USING FRACTURE ARRESTORS

As the interest for using all the technical solutions leading to the increase in the safety of operation of gas transmission pipelines has developed, the authors drew up a procedure for establishing the necessity and the usage features of the fracture arrestors on such pipelines.

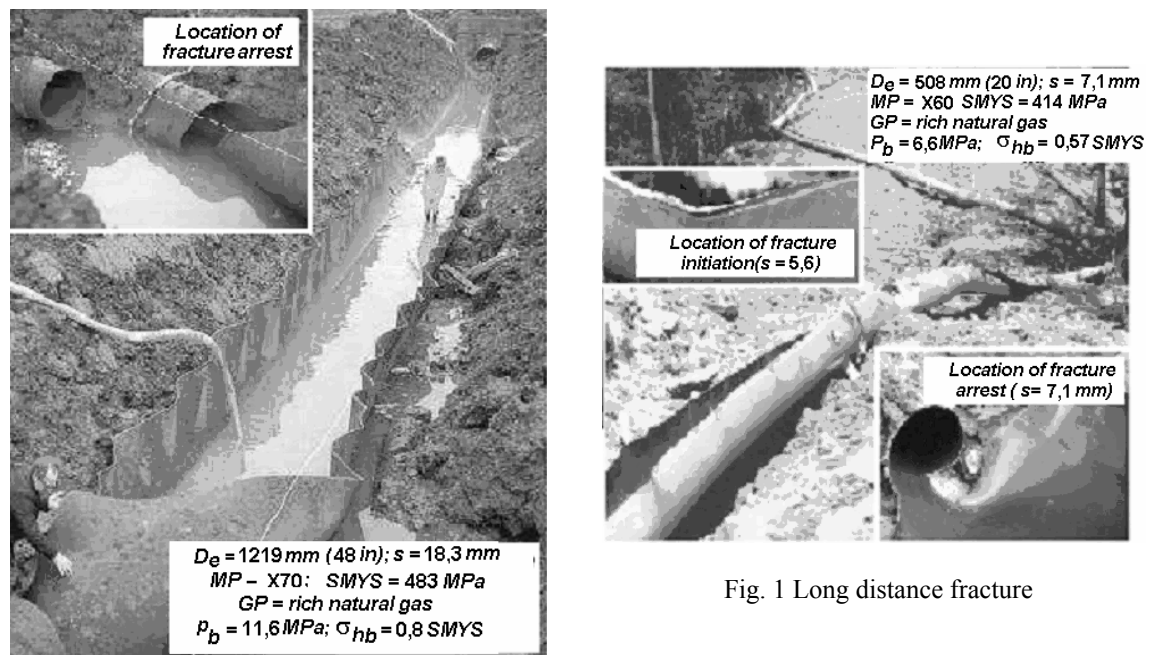


Fig. 1 Long distance fracture

Table 1 Features of pipelines fracture behavior

Fracture speed v_c , m/s	$v_c = 120 \dots 240$	$v_c = 240 \dots 450$	$v_c > 450$
Fracture appearance			
Fracture type	Ductile shear	Mixed fracture	Brittle chevron / cleavage
Fracture patterns	1 crack path Arrest possible	1 or 2 paths	Multiple paths

The first step of this procedure consists of establishing the data base concerning the technical features of the pipelines. Such data can be categorized as follows: a) data concerning the technical condition for operating the pipeline: the operating pressure p , the minimum working temperature t_w (or T_w), the physical – chemical features of the transported gas; the chemical composition, specific gas heat ratio y_g , molecular weight of M_g gas, sound speed in v_{sg} gas, etc.; b) data concerning the mechanical properties of the steel of the pipeline tubing: elastic module E_s , Poisson's ratio μ_s , tensile strength R_{ms} , yield strength R_{ts} or $SMYS$, the percentage after – fracture elongation A_s , fracture toughness (at t_w) FT_s , FT_s being the absorbed energy at Charpy impact stress KV_s , DWTT percent shear area $\%SA_s$ and/or DWTT energy DE_s , fracture toughness K_{cs} or J_{cs} , crack tip opening displacement/angle $CTOD_s$ or $CTOA_s$; c) data concerning the particular sizes of the pipeline: wall thickness s and outer diameter D_e (or the average diameter $D_m = D_e - s$).

The second step of the procedure consists of the assessment of the coordination between the pipeline mechanical stress features and the toughness features of the steel the pipeline is made of. To this effect, the maximum hoop stress intensity σ_h generated in the wall thickness by the pressure p of the transported gas, stress design factor F_d , toughness threshold KV_{as} , representing the minimum level of the steel toughness assuring the arresting of a fracture initiated on a local defect of the pipeline, the maximum hoop stress intensity σ_{ha} for which the prevention of a fracture growth takes place and gas pressure p_a which generates a hoop stress with σ_{ha} intensity in the pipeline wall [9,11,13]:

$$\sigma_h = p \frac{D_m}{2s}; F_d = \frac{\sigma_h}{SMYS}; KV_{as} = 0,000362 \sigma_h \sqrt{\sigma_h D_e}; \quad (1)$$

$$\sigma_{ha} = \frac{0,6 SMYS}{\pi} \arccos \left[\exp \left(- \frac{0,73657 \pi KV_s E_s}{SMYS^2 \sqrt{D_e s}} \right) \right]; p_a = \sigma_{ha} \frac{2s}{D_m}, \quad (2)$$

of which σ_h , σ_{ha} and p_a result in MPa, and KV_{as} in J, if p , $SMYS$, σ_h and E_s are introduced in MPa, D_e and s in mm, and KV_s in J. If the calculation results simultaneously suit the criterion $\sigma_{ha} \geq \sigma_h$, $p_a \geq p$ and $KV_a \geq KV_{as}$, they will decide that the fracture arrestors mounting on the pipeline is not necessary and the procedure is stopped.

The third step of the procedure consists of the assessment of the growth and stop possibilities of some fractures initiated on the pipeline through the Battelle two curve method application. The method consists of the representation on the same diagram of the crack velocity curve – *CVC*, relationship between the pressure at crack tip p_c and the crack velocity v_c , $v_c = f(p_c)$ and of gas decompression curve – *GDC*, relationship between the pressure p_d and the gas decompression velocity $v_d = g(p_d)$, analytically defined by the relations [9,13]:

$$v_c = C \frac{SMYS}{\sqrt{KV_s}} \left[\frac{p_c}{p_a} - 1 \right]^\alpha; \quad v_d = v_{sg} \frac{\gamma_g + 1}{\gamma_g - 1} \left[\left(\frac{p_d}{p} \right)^{\frac{\gamma_g - 1}{2\gamma_g}} - \frac{2}{\gamma_g + 1} \right], \quad (3)$$

in which C is a constant depending on the presence and type of backfill, and $\alpha = 1/6$, if the pipeline toughness is expressed by the level of absorbed energy at Charpy impact test KV_s . If no intersection exists between the *CVC* and *GDC* curves, gas decompression velocity exceed crack velocity for all pressure levels, the pressure at the crack front will decrease and the crack will arrest; on the other hand, if there is an intersection between the two curves, the pressure level where crack and gas decompression run together at the same velocity exist, no further decrease of the pressure at the crack front is possible and the crack will continue to grow. Thus, the tangent condition between the two curves represents the boundary between arrest and propagation and the corresponding toughness level is referred to as the arrest toughness by the Battelle two curve method. The results together with the software are summarized in figure 2 and are drawn up by the authors for the application of this method, in the case of a pipeline with $D_e = 813$ mm (32 in) and $s = 9,5$ mm, made of steel X60 ($E_s = 205000$ MPa, $SMYS = 414$ MPa), and which transports natural gas at $p = 6$ MPa pressure; it is obvious that, for this case, if $KV_s \leq 42.5$ J the persistence of the analysis about the usage of some fracture arrestors on the pipeline is rightful.

The fourth step of the procedure aims at determining the fracture growth distances to fracture arrest distance L_a when there is a pipeline failure. During this step diagrams as illustrated in fig 3 must be built and analyzed, diagrams which underline the fact that L_a values are influenced by the steel type the pipe tubing is made of, by the KV_s toughness values provided by this steel, by the stress level in the pipeline (expressed by the value of the design factor of the F_d stress). L_a values derived for the actual conditions of a pipeline, together with the information on the pipeline location of the most probable flawed areas which can initiate failure processes (welded joints produced in field conditions, aggressive soil areas, etc) and the current references (synthetically rendered in table 2) about the fracture arrestors allocation density based on the pipeline location, are used as input data for assessing the positions and distances between the fracture arrestors to be placed on the pipeline [3,4,11,13].

The fifth step of the procedure consists of the assessment and the selection of the solutions regarding the ensuring and the mounting of the fracture arrestors on the pipeline. The fracture arrestors are usually ensured as additional elements, placed on the pipeline tubing from place to place; their type can be of a wire winding or a band made of austenitic corrosion proof steel or of high plasticity non-ferrous alloys, wound-up on the pipeline tubing, the type of a CUS circumferentially girth weld on the tubing, using high toughness steel electrode or the type of a composite material coating. Currently, they mostly use the composite material fracture arrestors which are placed on the pipelines and are used when there is a failure process as presented in fig. 4. As there are no fracture arrestors design fundamental methodologies yet, their size is based on the results of some experimental research programs, as the ones presented in fig. 5 [3,7,8,11,12-15].

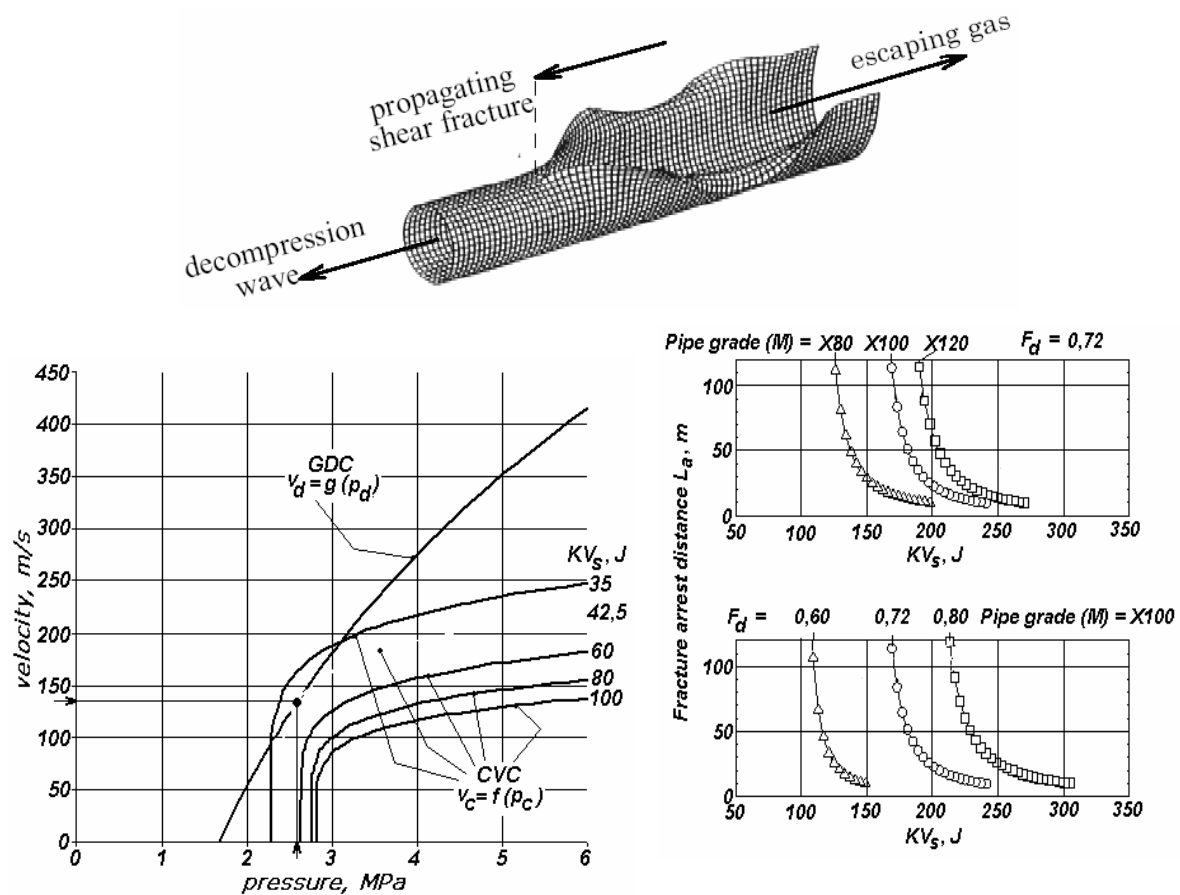


Fig. 2 Battelle two curve method results for the case of a pipeline with $D_e = 813$ mm (32 in)

Fig. 3 Fracture arrest distance L_a

Table 2 Fracture arrestors allocation density

Pipeline location	The distance / step between the fracture arrestors in the composite materials, m	The price of locating a composite material fracture arrestor, USD
1	300	1100 ... 1200 Without stopping the pipeline operating
2	250	
3	200	
4	150	

The usage of the fracture arrestors on the pipelines can be an economical solution in many applications regarding the safety of operation in acceptable safety and technical risk conditions for natural gas transmission pipelines. An example: a big company saved several million dollars by using Clock Spring fracture arrestors to avoid pipe replacement in converting a liquid pipeline to natural gas service in South Africa. The project involved the conversion of an $D_e = 457$ mm (18 in) pipeline, designed and constructed in accordance with ASME B31.4 for liquid service, to gas operation under ASME B31.8. The analyzed solutions and the advantages of the fracture arrestors usage to assure the pipeline operating safety features corresponding to the usage of the natural gas transport result from the analysis of the information summarized in table 3 [15].

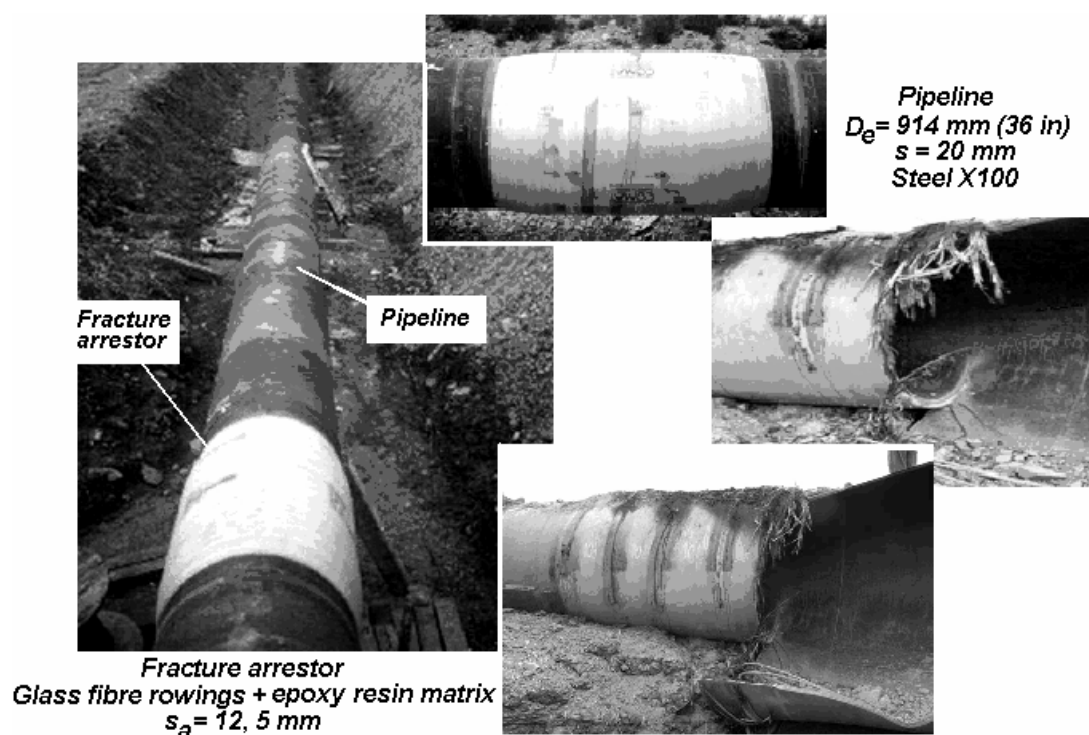


Fig. 4. Fracture arrestor from composite material coating

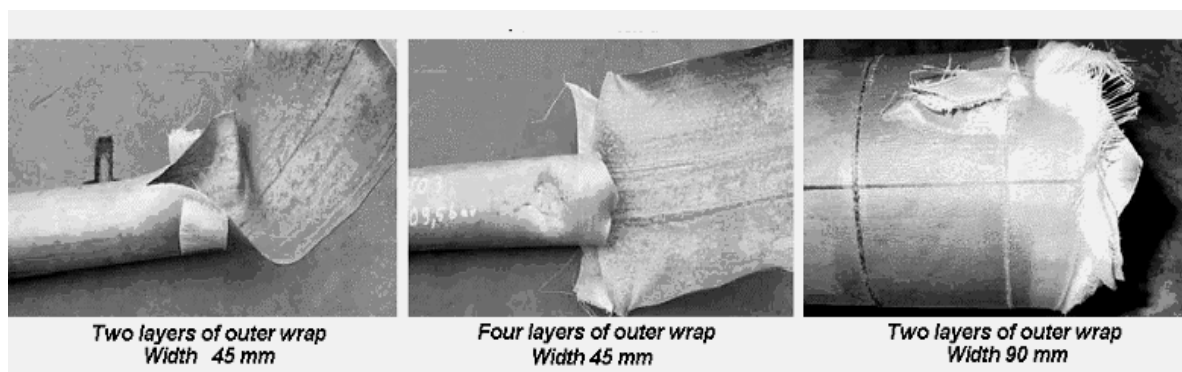


Fig. 5. Tests on crack arrest

Table 3. Advantages of the fracture arrestors usage

Operating pressure (gas pipeline)	Actions needed	Cost pipe replacement, USD	Cost fracture arrestors, USD
up to 3,9 MPa	No limiting factor	0	0
up to 4,9 MPa	Install 238 fracture arrestors	0	280000
up to 5,9 MPa	Replace 1,8 ... 2,0 km of pipe and install 619 fracture arrestors	700000	700000
up to 70 MPa	Replace 47,6 km of pipe and install 1659 fracture arrestors	16450000	1850000
up to 70 MPa	Replace 214,5 km of pipe	73830000	0

3. CONCLUSIONS

The usage of fracture arrestors assures the growth of the safety of operation and decreases the risk of generating and the consequences of pipeline failure for the natural gas transmission.

The application of the procedure proposed in the paper allows for the explanation of the usage and the establishment of the conditions regarding the fracture arrestors on the gas transmission pipelines.

REFERENCES

1. Azevedo C.R.F., Sinatora A., Failure analysis of a gas pipeline, *Engineering Failure Analysis*, 11, p. 387-400, 2004
2. Baek J., ș.a., Comparative study for various repair methods of in-service pipeline using full scale burette test, 23rd World Gas Conference, Amsterdam, 2006
3. Brauer H., Knauf G., Hillenbrand H., Crack arrestors, 4th International Conference on Pipeline Technology, Ostend, Belgium, 2004
4. Demofonti, G., Mannucci, G., Barsanti, L., Spinelli, C.M., Fracture behavior and defect evaluation of large diameter, HSLA steels, very high pressure line pipes, 2000 International Pipeline Conference, Vol. 1, p. 537-545, Canada, ASME 2000
5. Donoghue P.E. & a., The development and validation of dynamic fracture propagation model for gas transmission pipelines, în *Int. J. Pres. Ves. & Piping*, p. 11-25, November 1997
6. Dutta B.K., ș.a., Application of a modified damage potential to predict ductile crack initiation in welded pipes, în *Pressure Vessels Piping*, 82, p. 833-839, 2005
7. Leis N.B., Eiber J.R., Fracture propagation control in onshore transmission pipelines, Onshore Pipeline Technology Conference, Istanbul, p. 2.1-2.35, December 1998
8. Mannucci G., s.a., Fracture Properties of API X100 Gas Pipeline Steels, *Proceedings of the 13th Bienial EPRG – PRCI Joint Technical Meeting*, New Orleans, 2001
9. McGuire P. A., & a., A theoretical model for crack propagation and crack arrest in pressurized pipelines, *ASTM STP 711*, p. 341- 358, 1980
10. Martinez L.J., Rodriguez E., Developing tolerable risk criteria for gas transmission pipelines, 2000 International Pipeline Conference – ASME 2000, vol.1, p.63-69, Canada, ASME 2000
11. Okaguchi S., & a., Crack arrestability of high-pressure gas pipelines by X100 or X120, 23rd World Gas Conference, Amsterdam, June 2006
12. Porter C.P., Patrick A.J., Using Composite Wrap Crack Arrestors Saves Money On Pipeline Conversion, *Pipeline & Gas Journal*, p. 65-67, October 2002
13. Pokutyłowicz N., & a., Simulation of dynamic ductile failure in pipelines, 2000 International Pipeline Conference, Vol. 1, p. 279-285, ASME 2000
14. Zecheru Gh., & a., Remedierea defectelor depistate pe materialul tubular al conductelor de transport, Raport final la contractul nr. 13/2006, TRANSGAZ – UPG, Ploiești, 2006
15. * * * Clock Spring – The fast economical solution for permanent pipeline repair, Catalog 2006