QUANTITATIVE ACOUSTIC EMISSION NDI FOR ANALYSING DYNAMIC FRACTURE

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ABSTRACT: Quantitative Acoustic Emission (QAE) technology, physical and mathematical models were created for the reliable identification and evaluation of the danger level (the *J*-integral value) of a developing main crack in a system of interacting micro- cracks. They also enabled the reliable assessment of the remaining lifetime of low density polyethylene (LDPE) reactor tubes that contain cracks. These innovations made it possible to carry out pioneer investigations and establish previously unknown dependences, phenomena and criteria, such as:

- Interdependence between the *J*-integral value of the revealed flaw and the remaining lifetime of steel tubes that contain a system of inclusions, micro-cracks or had undergone stress corrosion cracking (SCC) attack and/or hydrogen embrittlement.
- Criteria for tube rejection.
- The optimal interval between repeated inspections (monitoring) of the reactor together with the time of analysis and decision.
- Criteria for acceptable flaw danger level that would allow continued use of tubes in operation for two years.

We established that a main crack in a system of micro-cracks under dynamic pulse loading could start to propagate earlier and faster, and reach greater lengths and take longer time to brake than an individual main crack. At the same time it was shown that the remaining lifetime could significantly decrease when a main crack interacts with a field of micro-cracks. The danger level (the *J*-integral value) of combined flaw increases significantly and may cause a catastrophic failure within a few weeks. Therefore, in this case, only continuous monitoring can eliminate the risk of tube failure.

Tension tests, optical and electron fractography, micro-sclerometric and AE image recognition investigations, spectral and chemical analysis, time of flight diffraction (TOFD) and X-ray techniques, all established a good correlation between the results obtained from compact steel specimens, full-size tube specimens tests, LDPE reactor tubes examinations and theoretical calculations.

MOTIVATION: Previously, the QAE Image Recognition method for revealing, identifying and assessing flaws in LDPE reactors, operating at high pressure of 3000 bar (43,500 psi) has been developed and discussed in several papers (Muravin et al., 1999, 2000a). This enabled increasing the operational safety of reactors and reducing the risk of unexpected and rarely predictable failures. Nevertheless there were no:

- Reliable methods for assessing the remaining lifetime of LDPE reactor tubes with individual cracks or systems of cracks having known *J*-integral values.
- Relevant design criteria for acceptable *J*-integral values of flaws for the specific tubes and criteria for rejecting tubes from operation.
- Universal tools for analytical or numerical assessment of flaws in tubes that undergo dynamic loading.

These problems have motivated the authors to create and develop technology for the reliable assessment of the remaining lifetime of LDPE reactor tubes that contain individual and multiple flaws.

METHODS FOR EVALUATING THE REMAINING LIFETIME OF TUBES WITH FLAWS UNDER CYCLING PRESSURE: To correctly evaluate the remaining lifetime of tubes of LDPE reactors, it is preferably to use the *J*-integral criteria because:

- Material of tubes for LDPE reactors is elastic-plastic and the influence of the plasticity on the crack growth can not be neglected.
- Critical *J*-integral value is a material property and does not depend on the scale and shape of the structure being tested.

- Total *J*-integral value takes into account the energy spent on creating a new surface and on plastic deformation development.
- *J*-integral is functionally connected with the AE parameters of the developing fracture.

One of the widely used methods for characterizing fatigue crack growth in elastic-plastic materials and for the evaluation of the remaining lifetime is based on the power law $dl/dN=C(\Delta J)^n$, where C and n are material constants and ΔJ is the cycling version of the *J*-integral (Viswanathan, 1993). To obtain reliable and accurate results using this law, material plasticity, temperature and current flaw geometry should be taken into consideration.

Despite the fact that accurate results were obtained in laboratory investigations of cracks growth in specimens there are many obstacles which decrease the accuracy and reliability of evaluating remaining lifetime of tubes in field conditions due to specific limitations of the conventional NDT methods (strain monitoring, replica method, UT, TOFD, Eddy current, etc.).

Using the QAE method, it is possible to improve the reliability of a remaining lifetime evaluation of a structure because it:

- Provides necessary information about the kinetics of crack development.
- Assesses the *J*-integral value of the main crack, taking into account the influence of inclusions and micro-cracks.
- Monitors the *J*-integral value under real operational conditions.
- Guarantees early detection of inner, outer and imbedded flaws.
- Accomplishes complete inspection of the entire structure for flaws.

PROCEDURES AND TECHNIQUES:

Test of Full-Size Tube Specimens. The Specifics of AE Signal Acquisition. Full-size tube specimens were tested by cyclically varied hydraulic pressure. The average pressure, $(P_{max}+P_{min})/2$ was increased during the test according to the law presented in Fig. 1. The cycling pressure variation, $P_{max}-P_{min}$ was equal 400 bars (5,800 psi) during the tests. The tube specimens were produced from the specific carbon steel which is commonly used in LDPE reactors. The specimens were 1m (39.4 in) long with internal and external radii equal to 39mm (1.54 in) and 105mm (4.13 in) respectively. In the internal surface of the tubes, an initial notch 25mm (0.98 in) long and 10mm (0.39 in) deep was induced by a special technique. The tests were performed at room temperature. The loading and AE data measuring were performed by specially designed equipment. The AE measurements started when the UT showed an increase of the crack notch depth by 2mm (0.079 in). The AE measurements were performed periodically after certain amount of cycles as specified in Fig. 1 (Points 1-8), while holding constant pressure at 3000 bar (43,500 psi). Before each AE measurement, UT examination was performed to evaluate intermediate crack geometry. Continuous and burst AE signals were recorded and analyzed for revealing flaws with low stress intensity and for monitoring kinetics of their development. This required new procedures and techniques for acquiring and decoding AE data in order to accomplish a reliable and precise evaluation of the *J*-integral of flaws.

The AE signals were recorded using Mistras 2000 AE equipment. Wide band sensors (50-500 kHz) with known amplitude-frequency characteristics were used. The AE data recorded included time of signal arrival, their amplitude, energy, RMS, counts, duration, rise time, counts to peak, average frequency and waveforms. The measured and estimated average signal amplitude loss from the structure to the sensors and to the AE devise did not exceed 3dB.

Flaw types and their danger level (*J*-integral value of a crack) were determined by analyzing the ellipses of dispersion (confidence area representing region of 97% probability of a normally distributed process) of the AE signals. The AE parameters that had been extracted from the recorded data were compared with AE fingerprints (the flaw type-stage-material specific ellipses of dispersion) in our database. This and other information about our laboratory investigations of specimens and field examination of tubes have been previously published (Muravin et al. 1999, 2000a).

Investigation of Correspondence between AE and Fracture Mechanics Properties of the Steel. A correlation between the AE and fracture mechanics characteristics of the LDPE reactor steels was established previously by simultaneous analysis of AE data that had been acquired when compact specimens with fatigue cracks were tested. The specimens were prepared in accordance with ASTM standard for evaluation of fracture toughness (J_{1c}). AE measurements were performed under monotonically increasing load.

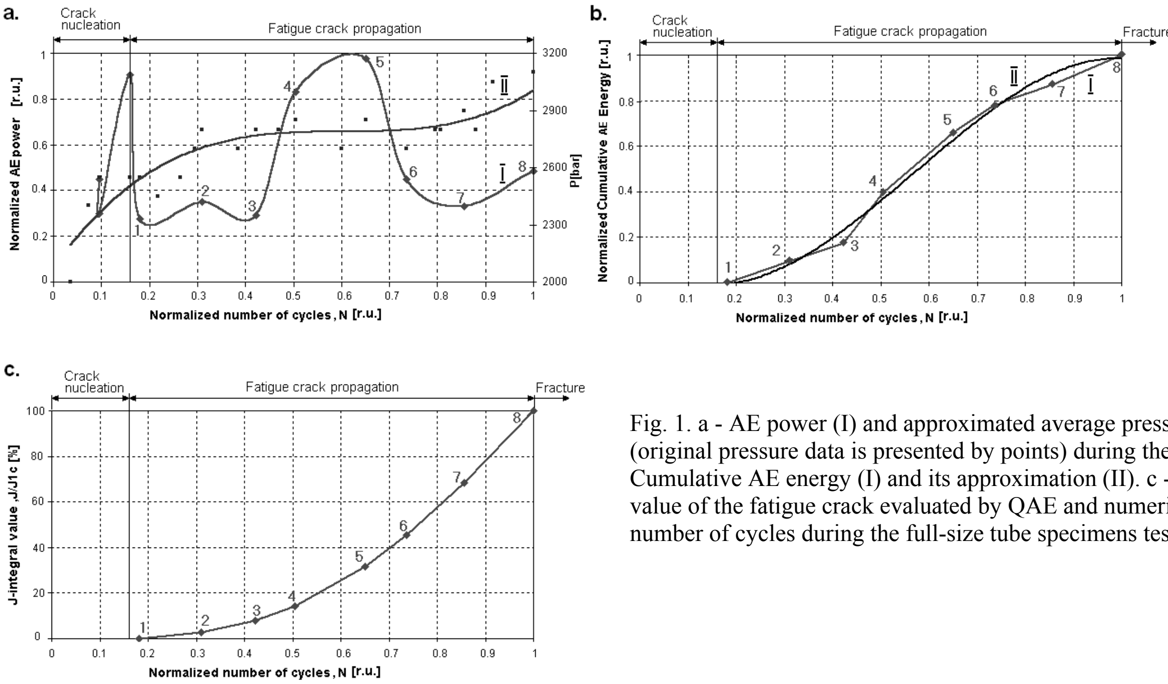

Fig. 1. a - AE power (I) and approximated average pressure (II) (original pressure data is presented by points) during the test; b - Cumulative AE energy (I) and its approximation (II). c - *J*-integral value of the fatigue crack evaluated by QAE and numerically vs. number of cycles during the full-size tube specimens test.

The stages of fracture development in specimens were determined according to methods described in previous reports and articles (Muravin et al., 1999, 2000a). Laboratory investigations established the uniqueness of the AE signals for different stages of crack development and revealed:

- The interdependence between the AE ellipses of dispersion and the *J*-integral value (evaluated numerically) of flaw at different stages of its development.
- Empirically linear relation between AE power and mechanical energy for specimens with a crack in the steel in original condition and in the steel with SCC.
- The standard deviations of AE characteristics (axes of ellipses of dispersion), for different ranges of *J*-integral value of flaws were acceptable for practical diagnostic purposes. Those stages of flaw development that are important for industrial purposes can be distinguished with an accuracy of not less than 90%.
- Flaws can be detected under the operating conditions with a reliability of at least 90%, if their *J*-integral value is about $0.05J_{1c}$. The reliability increases to about 95%, when flaws have *J*-integral value greater than $0.1J_{1c}$.

AE Data Decoding. Determining a Flaw type and Evaluating its Danger Level. The analysis of the collected data revealed the presence of continuous and burst AE signals in the tested tube. This might indicate the presence of flaws and potentially dangerous zones, leaks, friction in the supports, vibration of the tubes against the supports and consequent background noise, and AE sources associated with other factors.

Out of the aforementioned potential sources of AE, we tried to identify the AE sources associated with flaw development and isolate them for the analysis.

Elimination of the background noise started with a preliminary investigation of the graphs of AE energy signals. This showed the presence of AE signals with:

- Low energy similar to continuous AE (Group 1).
- Median energy about 20-25% higher than of signals of Group 1 (Group 2).
- High energy (Group 3).

The analysis of AE signals "energy-average frequency" normal probability density graphs (see example in Fig. 2) established that the AE signals of Group 1 were observed in the tube specimens during all the measurements and made up more than 95% of the total number of recorded AE signals. It was assumed that the AE signals of Group 1 represent background noise. This assumption was confirmed by comparison of records at all stages of crack development. Consequently, the AE signals of Group 1 were eliminated from subsequent consideration by a special non-linear filtering.

It also established that signals of Group 2 (see Fig. 2) have typical indications associated with the development of plastic deformation around flaws with low stress intensity. Such flaws are usually associated with plastic deformation development and were previously observed by us in the laboratory and during field inspections (Muravin et al., 1999, 2000a, Finkel, 1977).

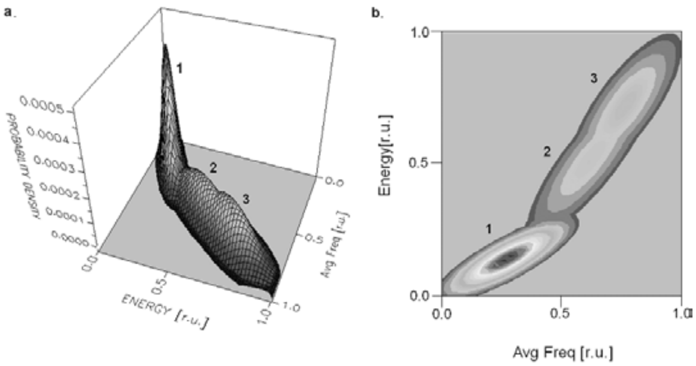

Fig. 2. Example. Three-dimensional graphs of normal probability density (a), and ellipses of dispersion (b) of AE signal “energy-average frequency”. Groups of AE signals associated with: 1. Background noise. 2. Plastic deformation development. 3. Individual micro-cracking. J-integral value of about $0.1J_{1c}$.

Signals of Group 3 (see Fig. 2), which had the highest energy and frequency, appeared relative rarely. The characteristics of such AE signals’ are usually associated with the development of flaws with higher stress intensity, such as cracks and micro- cracks, and stress corrosion cracking. Therefore, it was assumed that they were associated with nucleation and the growth of flaws resulting from the test pressure.

Based on these observations and assumptions, we:

- Carried out non-linear filtering of the background noise (signals of Group 1).
- Plotted the normal probability density graphs of AE signals “energy-average frequency” for all data (see example in Fig. 2).
- Calculated and compared changes of AE power and pressure vs. number cycles (Fig. 1a).
- Calculated the variation of cumulative AE energy vs. number cycles (Fig. 1b).
- Evaluated the J-integral value of crack vs. number of cycles (Fig. 1c) numerically using independent information about flaw geometry.
- Confirmed J-integral value of flaw comparing corresponding AE data to the results obtained during laboratory investigations of specimens (Fig. 3).

It should be noted that the AE measurements were performed while holding pressure at 3000 bar (43,500 psi). The calculated J-integral values in Fig. 1c correspond to this loading condition. The x-axis in Fig. 1 represents the number of cycles performed on tube specimen prior intermediate AE measurements (Points 1-8 on Fig. 1) and UT measurements of the crack geometry. The numerical calculation of the J-integral value was performed taking into consideration current crack geometry, the material properties of the steel under ambient temperature and constant pressure of 3000 bar (43,500 psi).

For evaluation of the flaws type and its danger level (the J-integral value) the AE signals that were recorded and separated by non-linear filtration from background noise were combined into ellipses of dispersion and compared with AE fingerprints of:

- Different stages of flaws propagation in the specific material.
- Local plastic deformation around inclusions.
- Fracturing of hard inclusions.
- Stress corrosion cracking, hydrogen embrittlement.

The flaw danger level was evaluated from the maximal overlapping of AE fingerprints that were obtained in laboratory investigation of compact steel specimens with ellipses of dispersion of fatigue cracks developing in the examined tube specimens. The results of the flaw danger level evaluation are presented in Fig. 3. Here AE data measured after the number of cycle, corresponded to the position of Points 2, 3, 4, 5 in Fig. 1 compared to ellipses of dispersion, AE fingerprints of cracks that have danger levels: I - $J<0.05J_{1c}$; II - $0.05J_{1c}\leq J<0.1J_{1c}$; III - $0.1J_{1c}\leq J\leq 0.2J_{1c}$, IV - $0.2J_{1c}\leq J\leq 0.3\ J_{1c}$. Specifically the QAE analysis established that the flaw at Points 2-5 (Fig. 1) had a J-integral value of 0.0-0.5J_{1c}, 0.5$J1c$-0.1J_{1c}, 0.1-0.2J_{1c}, 0.2-0.3J_{1c} respectively. The results of the analysis demonstrate a good correlation between the J-integral evaluations by the QAE method (Fig. 3) and those calculated numerically in Fig. 1c.

The analysis of the AE data measuring has shown (Fig. 1a) that AE power was not growing uniformly at different stages of tube deformation. The peak of AE power corresponded to 0.16N (N is total number of cycles to failure, see Fig. 1a) and is associated with the dissipation of energy during nucleation of a fatigue crack. This was confirmed primarily by comparison of AE ellipses of dispersion "energy – average frequency" recorded during the current test with information collected in our data base. In addition to this, an increase of the notch and crack initiation was observed during UT examination of the tube.

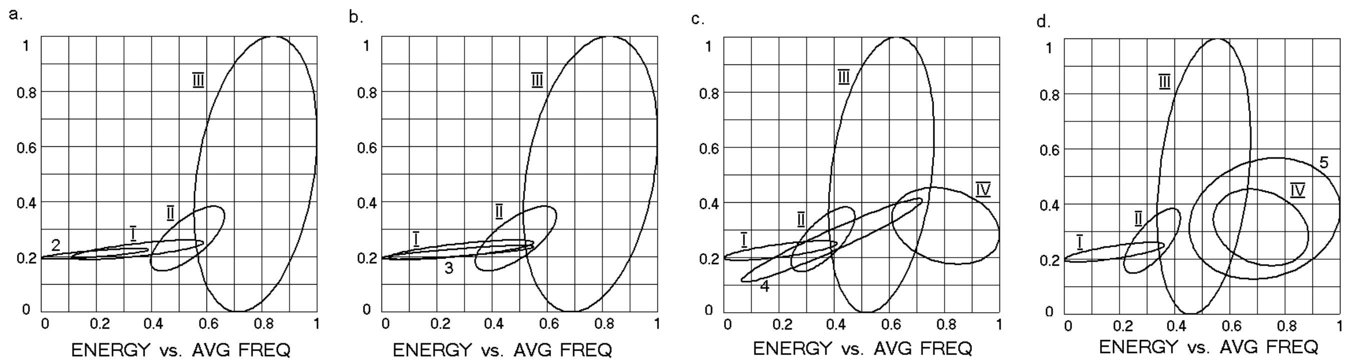

Fig. 3. Example of flaw danger level evaluation. Comparison of ellipses of dispersion of AE signals "energy-average frequency" recorded in compact specimens with fatigue crack (ellipses I-IV corresponding to 0.0-0.05 J_{1c}, 0.05-0.1J_{1c}, 0.1-0.2J_{1c}, 0.2-0.3J_{1c} stages of flaw development) with data recorded during the test of the full-size tube specimens (ellipses 2-5 corresponding to AE measurements marked by Points 2-5 in Fig.1).

The crack's opening without its elongation (0.175-0.42N, Fig. 1a) was accompanied by intensive plastic deformation and intensive continuous AE. The subsequent cycling loading (up to 0.65N, Fig. 1a) led to significant crack elongation; appearance of high number of burst AE signals, increased dissipation of mechanical energy and subsequent growth of the AE power.

Continuous cycling loading of the tube (0.72-1.0N, Fig. 1a) led to massive plastic deformation in the region surrounding the crack tip and plastic collapse of specimen. The AE power decreased at this stage. The AE energy flow had characteristic indications of continuous AE with faintly seen signs of the presence of burst signals.

One can see that the AE power and cumulative AE energy increases more significantly from Point 3 to Point 5 (Fig. 1a,b). Then the rate of energy dissipation decreases due to increasing plasticity. The area under the curve of cumulative AE power vs. number of cycles increases continuously (see Fig. 1b) indicating the growing danger level (the J-integral value) of the fatigue crack (Fig. 1c).

It is necessary to point out that the time interval for discrete monitoring should be significantly less than the remaining lifetime of the tubes with flaws that could be revealed during AE monitoring under operating conditions. To satisfy such requirements it is necessary to determine the lifetime expectation of tubes with cracks that have different J-integral values. Our experiments satisfied these requirements. The test of a number of tube-specimens under conditions as close as possible to the operational has showed that:

- The flaw detection sensitivity in LDPE reactor tubes should be lower than 0.1J_{1c} (at present, the sensitivity of our technology is less than 0.025J_{1c}).
- Tubes with individual fatigue cracks that have a J-integral value close to 0.1J/J_{1c} could fail within one year. The deviation of results was of about 10%.
- The rejection of a tube should be considered if it has one or more individual flaws, or a system of flaws with a J-integral value greater than 0.1J_{1c}. In practice, it is not necessary to distinguish between individual defects or a system of defects, if one of them has a J-integral value higher than 0.1J_{1c}.

Proposed criteria for tube rejection corresponds to other comparable applications (high energy piping of nuclear and fossil power plants). In these applications, the J-integral value equal to 0.1J_{1c} was used as the threshold level for rejection (replacement or repair) of piping.

EVALUATING REMAINING LIFETIME TUBES IN ORIGINAL CONDITION:

General. Evaluation of the remaining lifetime of tubes with fatigue cracks operating under cyclic loading requires the determination of the expected number of cycles to failure or to a particular moment, when the possible catastrophic failure can be prevented. This is can be accomplished by using information about:

- Current flaw danger level (*J*-integral value).
- Dependence of the average length of crack jumps (Δl) vs. *J*-integral value.
- The number of crack jumps per cycle.

We have discussed the evaluation of the current flaw danger level earlier (G. Muravin et al., 1999, 2000a). The information about the number of cycles to a specific date is known. Therefore, it is necessary to find the method for determining Δl and the number of crack jumps per cycle.

Determination of Fatigue Crack Elongation Δl vs. *J*-Integral Value. Fatigue cracks of different length were created in 24 specimens of the steel used in LDPE reactors tubes. The specimens were then fractured by tension load and the length of crack jumps was investigated statistically to determine average the Δl *vs. J*-integral value. A method developed by Fridman and described by Finkel (1977) was used to measure fatigue crack elongation, Δl. Figure 5 provides an example of Δl findings performed by high-resolution electron fractography.

Statistical analysis of the Δl *vs. J*-integral value measurement has revealed the deviation in the length of crack jumps for the same *J*-integral value. The minimal deviation (of about 20%) is associated with short crack length. The maximum deviation (up to 40%) occurs close to the moment of unstable crack growth. It is important that one can observe the significant increase (up to five times) in the length of crack jumps when the *J*-integral value of a fatigue crack reaches its critical value, J_{1c}. This should be taken into consideration to decrease errors in calculating the remaining lifetime.

Correlation between Number of Fatigue Crack Jumps Revealed by Electron Fractography and Data Extracted from QAE NDI. An examination of specimens with fatigue cracks was performed to reveal the number of crack jumps per cycle using electron fractography and by recording AE parameters corresponding to micro crack propagation. The specimens were treated thermally after creating a primary fatigue crack to "color" the created surface. They were then loaded again for several cycles and fractured by tension load. The zone of fatigue crack propagation that was not colored was carefully investigated by raster electron microscopy and high resolution microscopy. This made it possible to determine the average number of cracks jumps and their length (*N* and Δl).

It is clear that the detection of a number of the crack jumps *N* at the fractured surface by means of electron fractography is far from perfect. The evaluation performed by different authors leads to the conclusion that the accuracy of such measurements is about 70%. Similarly, the information extracted from AE accompanying fracturing also demands specific improvements to satisfy the requirements for revealing the characteristics corresponding to crack jumps.

A set of measures was performed by us to increase the accuracy and reliability for determining characteristics of crack jumps. Currently, the errors in recognizing between plastic deformation and micro-cracking are less then 10%. Nevertheless, the accuracy of calculating *N* determined by AE measurements must still be assumed to be 70%, due to the absence of reliable means for verifying results other than electron fractography. The results achieved, however, are acceptable, compared with the information that can be extracted from existing industrial measurements.

Method Used for Evaluating Condition of a Tube with an Individual Crack. The theoretical calculation of remaining lifetime was performed on the assumption that:

- The tubes operating under cyclic loading.
- The tubes contained single fatigue crack, and its initial *J*-integral value is known.
- The dependence of the average length of crack jumps *(* Δl) vs. *J*-integral for the specific material is known.

The aim of the calculation was to determine the expected number of cycles, *N* to failure. The problem was simplified by considering a plate with a crack loaded by a cyclically applied pulse stress. This simplification is required since no numerical method is presently available which calculates, on regular computers, an accurate and reliable numerical solution for densely located multiple interacting dynamic cracks in 3D structures subjected to pulse loading. The pulse loading conditions were selected to model the operational conditions of LDPE reactors, in which there is an instantaneous change of pressure on 300-400 bars (4,350-5,800 psi) every few seconds. The principal possibilities of dynamic diagnostics of the materials in these conditions have been described earlier (Muravin et al., 2000b). The problem was solved numerically by the Element Free Galerkin meshless method. This was specially modified for the solution of dynamic single and dynamic multiple cracks (B. Muravin et al., 2002).

Results of Lifetime Evaluation for Tube with Individual Crack. The analysis has shown (see Fig. 4, curve 1) that flaws with a danger level $0.1J_{Ic}$ (under maximum pressure) may cause a failure of a reactor tube within 11 months under its normal operational condition. Fatigue cracks that have a danger level $0.2J_{Ic}$ fail within 3 months. A less drastic prognosis of operational safety can be made for tubes that contain fatigue cracks with J-integral values of $J<0.05J_{1c}$. Such tubes can remain in operation for more than three years. Based on the above it is possible to create a basic plan for inspecting and monitoring LDPE reactors and to establish requirements to sensitivity of NDI methods to be used for revealing flaws.

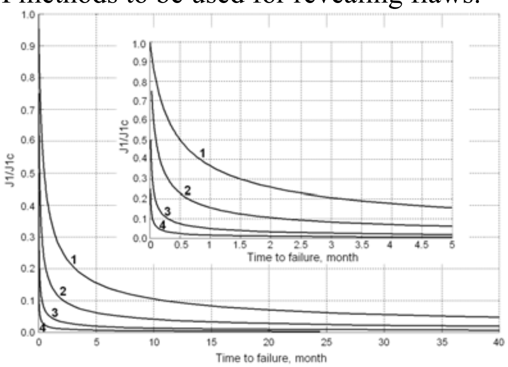

Fig. 4. Remaining lifetime for LDPE reactor tubes:
1. Tube with fatigue crack in metal in original condition.
2, 3, 4 tubes with a system of micro- cracks in brittle metal with reduced fracture toughness J_{1c}* compared with a metal in original condition (2 - J_{1c}* =0.75 J_{1c}; 3-

The results of the calculations were compared with observations during failures of LDPE reactor tubes. Several cases of failures were re-examined, and their history, nature and cause were investigated properly. Failure analysis was performed with high resolution electron fractography.

We were fortunate to find zones of initial crack nucleation in good condition, as well as the zone of the main crack propagation. These enabled us to find the dimensions of the original source of fracturing (a fatigue crack that appeared as a result of the interaction of micro- cracks around systems of inclusions) and to evaluate the danger level of the initial cracks. We were also able to establish the average length of crack jumps (Δl) and the associated increasing J-integral for the specific material. All of this together with information about the previous inspection of fractured tubes made it possible to estimate their remaining lifetime.

Thus, a failure analysis of failed LDPE reactor tubes with a fatigue crack that had an initial danger level $0.1J_{Ic}$ have shown that the crack developed to its critical size within nine to eleven months, while a tube with fatigue cracks that had an initial danger level $J<0.05J_{Ic}$ failed within three to four years. The results indicated a close correlation between the calculations and actual facts. Nevertheless, the limited number of real failures that were available for analysis indicated the need to continue laboratory investigation of tubes fracturing in order to increase the reliability of theoretical calculations of remaining lifetime.

Based on the above it is possible to conclude that using NDI methods that can reveal flaws with danger levels of $J<0.05J_{Ic}$ one can guarantee the safety of LDPE reactor operation for two years with a coefficient of safety of about 1.5. When monitoring flaw development in operating reactors with intensive background noise, the flaw safety factors should be increased by at least on 50%. This will reveal more severe flaws that have $0.05J_{Ic}\leq J<0.075J_{Ic}$ one year before the moment of tube failure. Accordingly, personnel will have information about the possibility of failure much earlier and in good time to prepare tube rejection and replacement.

Remaining Lifetime Evaluation for a Tube with a System of Inclusions that has Undergone SCC and/or Hydrogen Embrittlement. Earlier we showned that both SCC and the diffusion of hydrogen lead to the formation of inter-granular cracks, which develop systems of interacting cracks (Muravin et al., 1999, 2000a). The situation becomes most dangerous, when local concentration of inclusions in tubes undergo de-bonding, which usually leads to initiation and subsequent propagation of micro- cracks. These flaws with low stress intensity raise the following specific difficulties:

- Revealing them by local NDI inspection or by using burst AE is problematic.
- Evaluating the remaining lifetime of tubes with these flaws is extremely difficult and inaccurate.

- They can result in a catastrophic failure of a tube in a very short time.

Due to the lack of knowledge, unexpected and rarely predictable failures caused by systems of interacting flaws continue to occur in high-pressure equipment and high energy piping. To clarify the situation and find answers to specific practical problems we tried to assess:

- Remaining lifetime of LDPE reactor tubes in the above-mentioned conditions.
- The interval between necessary inspections in order to eliminate the risk of tube failure.

Calculations were performed using physical model and numerical methods created by B. Muravin et al. (2002). The analysis of the results established the following:

- The interaction of flaws decreases J_{1c} of the material about four times (earlier it were shown that SCC can decrease J_{1c} of different materials four to ten times).
- The interaction of a main crack with a system of micro-cracks may increase the velocity of the main crack propagation up to 2 times compared to the single crack development in homogeneous material.
- The crack may start to propagate earlier if interacting with other flaws and the steel contains inclusions and has undergone SCC (Fig. 4, curves 2, 3, 4).
- A main crack may elongate to a greater extent if it is interacting with other cracks.

All the above agrees with the results of tension tests, optical and electron fractography, micro-sclerometric, AE image recognition investigations, spectral and chemical analysis, TOFD, X-ray measuring obtained during specimens and tube-specimens tests, and LDPE reactor examinations. This explains why the fracture of tubes that contain systems of inclusions with SCC and/or hydrogen embrittlement can develop quickly and cause a failure of tubes within days. Such a fracturing scenario can only be eliminated by continuous QAE monitoring.

RESULTS AND CONCLUSIONS: 1. Quantitative AE technology physical and mathematical models were created for the reliable and precise identification and evaluation of the danger level (the *J*-integral value) of a developing main crack in a system of interacting micro- cracks and for the reliable assessment of the remaining lifetime of LDPE reactor tubes that contained cracks.

2. It was established that main crack in a system of micro-cracks under dynamic pulse loading could start to propagate earlier and faster, for larger lengths, and brake for a longer time than individual main crack.

The remaining lifetime and accuracy of lifetime evaluation could be significantly decreased as result of a main crack interacting with a field of micro-cracks. The *J*-integral value of combined flaw increase significantly and may cause a catastrophic failure within days. Therefore, in this case, only continuous monitoring can eliminate the risk of tube failure.

3. Tension tests, optical and electron fractography, micro-sclerometric and AE image recognition investigations, spectral and chemical analysis, TOFD, X-ray, all established a good correlation between results obtained during tests of steel compact specimens and full-size tube specimens tests, LDPE reactor examinations and theoretical calculations.

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