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Testing of the high- density polyethylene pipes for transporting the natural gas

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الملخص:

إن الغرض من هذا البحث هو برهنة إمكانية استخدام أنابيب مصنعة من مادة البولي إثلين "PE" بدلاً من استخدام أنابيب الصلب الكربوني "CS" في عمليات نقل الغاز الطبيعي.

فمنذ ستينات القرن الماضي هيمنت الأنابيب المصنعة من الصلب الكربوني في مجالات نقل المياه والنفط الخام بالإضافة إلى الغاز الطبيعي، حيث كانت تصنع بطريقة الدرفلة لشريحة من الصلب لتكون على شكل الانبوب ومن ثم تلحم طولياً بالقطر والسمك المحدد.

كما إن عملية التصنيع والصيانة وإعادة الطلاء تعتبر في حد ذاتها مكلفة، مع ضعف مقاومة الصلب للتأكل والصدأ وتأثير التربة، والتي تتطلب تطبيق إجراءات معينة تساعد في حمايته من العوامل السابقة، وهذا ما شجع على البحث عن استخدام مواد آخرى تحل محل الصلب الكربوني في مجال نقل الغاز الطبيعي.

حيث تعتبر عمليات تصنيع أنابيب البولي إثلين "PE" أقل كلفة وما تمتاز به من طول العمر وخفة الوزن وافتقارها لعمليات الصيانة، إذا ما قورنت بمادة الصلب الكربوني.

لهذه الاسباب، فإن هذا البحث يعد مبرهنة حسابية لإثبات انه بالإمكان استخدم انابيب البولي أثلين نوع PE100 عوضاً عن أنابيب الصلب الكربوني في عمليات نقل الغاز الطبيعي، عن طريق إعداد نموذج رياضي ثلاثي الابعاد بالوحدات المتناهية الصغر(Finite elements)، استعين فيه برنامج الحساب الهندسي الصولد ورك (Solid work)لاختبار حد الضغوط التشغيلية ومقارنتها بالضغوط المسموح بها لمادة البولي أثلين واختبار الاحمال الخارجية فوق الانبوب.

- **Abstract:**

The purpose of this study is to prove that the polyethylene pips (PE) can be used instead of the carbon Steel pipes (CS) for the reason of the natural gas transportation.

Since 1960's, the (CS) was in use for crude oil as well as water and natural gas transport from point to point, in which it was manufactured by many ways whereas wrapping the sheets of steel to the shape of the pipes using rolling machine then weld them to have a pipe in the final stage.

The whole manufacturing process is expensive and determines the working life of the pipelines for many reasons whereas the corrosion and resistance are the important ones. Moreover; the maintenance of the buried (CS) pipelines was needed from time to time to prevent leakage and maintain cathodic protection to soil resistance which add extra cost and limits, the age, of the pipes.

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The manufacturing process of the PE pipes is cheaper simpler, than (CS) as well as the lifetime of PE is longer than the (CS) which reaches up to 50 years of use, also it sufficient and less wight than the (CS) ones, in addition, it doesn't need the maintenance that the (CS) pipes needs.

Therefore, this research has proven that the PE can be used PE 100, for the purpose of the natural gas transportation based on the result obtained which has been taken and even has been experimenting the pressure limits (operation pressure) internally and externally by using the finite elements software (Solid-Work) which simulates the internal stresses in the pipes and external loads on it.

- **Introduction:**

Mulita Project is a Libyan natural gas project which aims to distribute the natural gas by transport it to power stations and factories around the country to be used as a fuel. Therefore; buried (CS) pipeline, were used to transport natural gas to the stations which located to western and eastern portions of the country (Libya). The networks of the distribution buried pipelines have to be investigated during its use to assure the joints and gas leakage which might they affected by the corrosion that occurs because of the soil resistance [1]. Moreover; the procedures of Pipes manufacturing make the whole project cost expensive compared to the lifetime of the pipes [2] [3] [4]. In addition, the wight of pipes is heavy and needs a specific equipment to move during the insulation and the burying procedure.

PE Pipes can be used for its material advantages such as less wight, soil resistance, lifetime, and no corrosion problems [5]. Also, it reduces the cost of the whole project. That why, a simulation is made to experience the internal and external pressure in order to decide whether the PE pipes can be the best fit of the purpose or not [6][7] it shown on the tables (1,2)

- **Analyses Method:**

In order to approve the polyethylene pipelines validity for the use of natural gas transporting, and its ability to yield the internal pressures and external loads, a 3-D sold work model has been built with the standards of PE pipes such as the material pressure limits and the pipes depth, also it has assumed to work under pressure of 10 bars of the natural gas working pressure for the given pipes ranges SDR (D/t) of 9, 11, 13.6, and 17 and the pipe length is 5 m free-edges as it shown on the table(1)[8].

In the simulation model, the PE pipe is assumed to be buried and exposed to the external loads due to the wight of soil which called dead loads, in addition to the moved wights above which called a live load. Meanwhile, the pipe exposed to the internal pressure due to the flow of the natural gas through it , therefore, the total experimental stresses have been applied to all SDR's .

- **The Internal Stresses:**

Due to the working pressure of the natural gas passing through the pipes, the stresses and strain appeared on the internal wall of the pipe needed to be calculated to assure the stress limits of the pipe [9] compared to the ultimate stress and those stresses are divided to the Hoop & longitudinal stresses as shown in figure (1) [10].

Table 1: The thickness and diameter of each SDR [8]

SDR	Di(mm)	Do(mm)	t(mm)	L (m)
SDR9	101.6	114.3	12.7	5
SDR11	103.9	114.3	10.39	5
SDR13.6	105.9	114.3	8.4	5
SDR17	107.6	114.3	6.7	5

Figure 2: lifetime and working temperature of each PE pipe [11,12]

PE 80B (M pa)	PE 100B(M pa)	Working Period (years)	Working temperature (ºC)
8.0	10.0	50	20
7.5	9.4	50	25
7.0	8.7	50	30
6.4	8.0	50	35
6.0	7.3	50	40

1- Hoop Stress:

Hoop stress is the vertical forces affecting the center and the radius of pipe during natural gas flow through the pipe, so it has to exam it in order to avoid the pipe explosion or the pipe failure, and it can be written as following equation:

$$\sigma\theta = \frac{Pi \times Di}{2 \times t}$$

Where:

Pi = the working gas Pressure (par).
Di= Internal diameter of the pipe (mm).
t = the thickness of the pipe (mm).

2- The Longitudinal Stress:

longitudinal stress is the horizontal forces affecting the pipe throughout its length and it is vertical on the unit of the pipe's area and can be represent by the following equation:

$$\sigma l = \frac{Pi \times Di}{4 \times t}$$

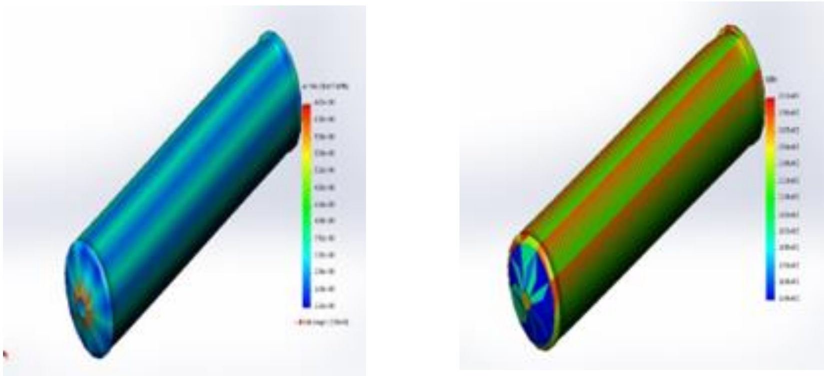


Figure 1: Sold-Work pipe model shows the internal pressure run

3- The Maximum allowed Pressure:
In order to maintain the validity of the pipe, the maximum allowed pressure has to be calculated according to the pipe material, thus, the equation can be represented [11]as:

$$P_{max} = \frac{2 \times F_{mrs}}{C(D_{sdr} - 1)}$$

Where:

F_{mrs} = the Limit of the requested force figure (2).

C = Design Factor

D_{sdr} = The rate of stander dimension

4- The principles Stresses (N/mm^2), [12],[13]:

$$\sigma max, \sigma min = \frac{\sigma x + \sigma y}{2} \pm \sqrt{(\frac{\sigma x - \sigma y}{2})^2}$$

Where:

. $\sigma x = the$ Longitudinal $stress$

$\sigma y = the\ Hoop\ Stress.$

- **The External Loads:**

The pipe is exposed to the wights of the soil, pavement above the soil, and the wights of the cars and trucks moved on it, and they represent as the external loads. These loads also titled as live & dead loads.

The simulation model is designed based on the depth of pipe 4.1 ft (1.25m) assuming the international standard of the polyethylene pipes and the soil wight of 120 Pound cubic feet (PCF) (2,002.30 Kg/m^3) assumed as a dry soil as shown in figure (2) [13].

The run of the model is simulating the pipe during operation where the natural gas is passing through external loads are moving on it at same time and gives the result according to that moment.

The inserted equation of the external loads can be written as the following:

$$Pe = W \times H$$

Where:

Pe= the vertical pressure of soil

W= wight of soil (PCF).

H= depth of pipe (ft).

Based on the American association of the high ways and transportation AASHTO the H20 of the heavy trucks is given by the following equation (Boussinesq Equation) [13]:

$$Pl = \frac{3 \times If \times Ww \times H^3}{2 \times \pi \times r^5}$$

$$r = \sqrt{x^2 + h^2}$$

Where:

If = impact factor given on table (3).

W_w= the truck wight (Lbs).

H= depth of pipe (m).

r = the distance between the load and the surface of pipe.

Table 3: cover of pipe vs. the impact factor [13]

Cover of pipe (mm)	Impact factor, $\boldsymbol{If}$
304.8	1.35
609.6	1.30
914.4	1.25
1219.2	1.20
1828.8	1.10
2438.4	1.00

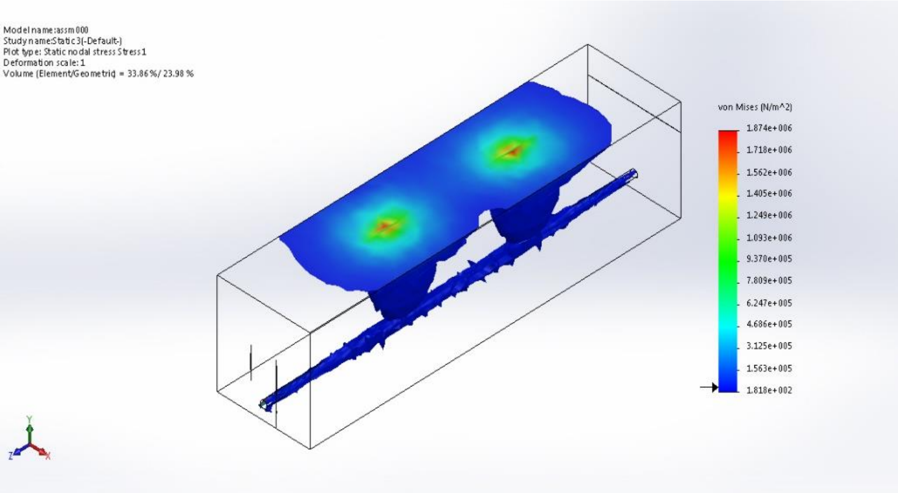
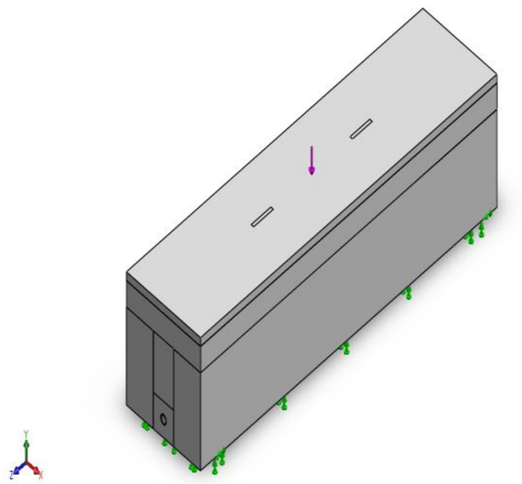


Figure 2: schematic figure of loaded pipe under soil

- ## The Model Results:

On the simulation, the internal stresses & external loads will be combined together on the pipe and will extracted in figures to examine the stresses and strains limits in order to decide the PE pipe validity to be used for the purpose of natural gas transportation.[14], [15].

The following figures has been taken on the moment when a heavy track moved on the pipe and it wight was 30000 bound and the natural gas was running in the pipe for each SDRs, as shown on figure (3)



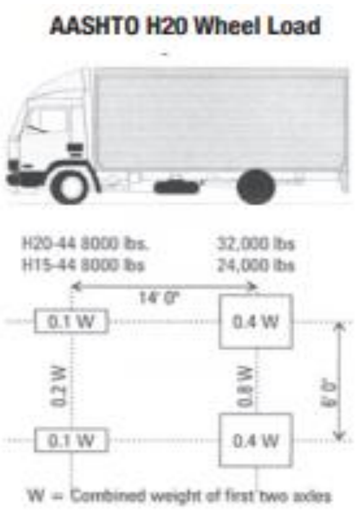


Figure3: Solid-Work model shows the external loads on pipe

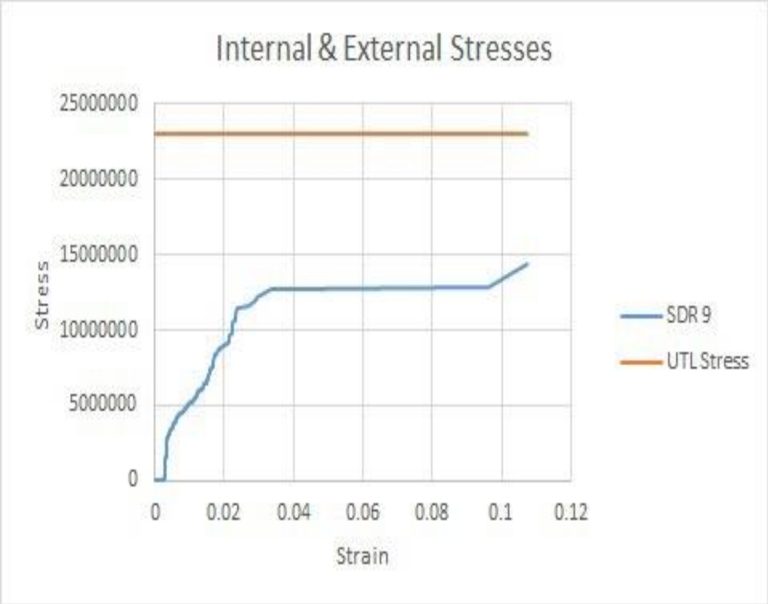


Figure4: Result for SDR9

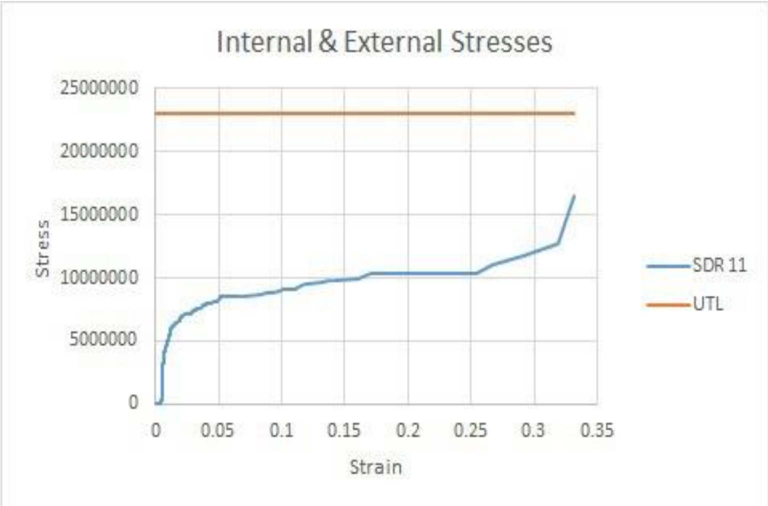


Figure5: Result for SDR11

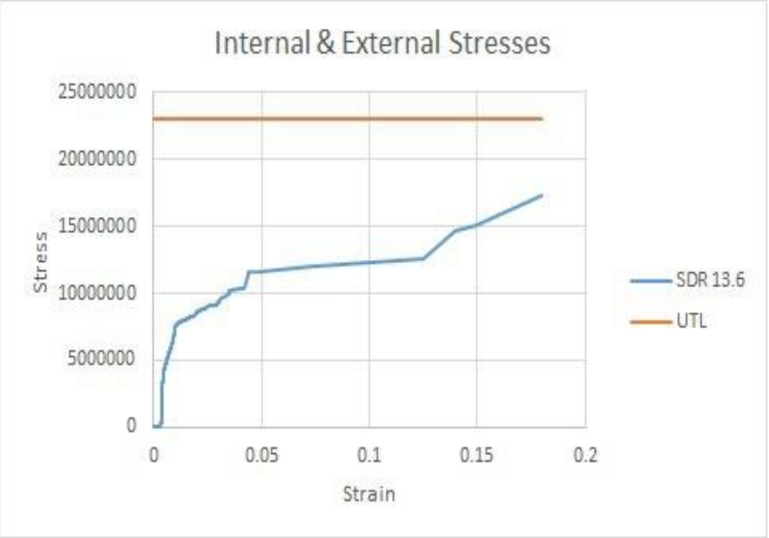


Figure6: Result for SDR13.6

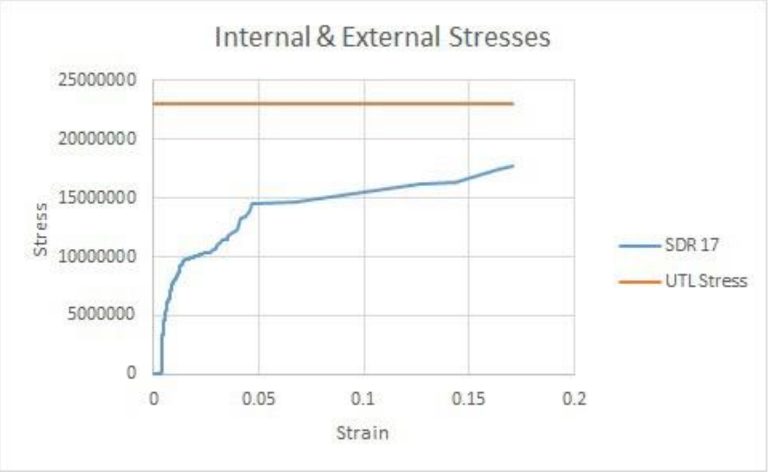


Figure7: Result for SDR17

- ## Conclusion:

As a result, the study has proven that the PE pipe can be used for the purpose of the natural gas transportation instead of the (CS) pipes under the condition of 11 bar maximum for the pipeline networks.

Also, the SDR 9 can expose to 20 bar if the thickness of it 12.7 mm in case of the internal pressure and to the 14.449 (N/mm^2) for the external pressure.

moreover, the condition of the pipe's external load (soil weight and moving loads) which has calculated at the pipe's depth 1.25 m. can be improved if the pipe's depth is deeper.

Eventually, if the PE pipe thickness for the SDR 11 & 13.6 are thicker, the results will be better and the PE pipes can be undergone to 24 bar as a working pressure and will be valid to transport the natural gas to the electric power plants which are the concern for the next research.

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