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STRESS STUDY ON NATURAL GAS PIPING SYSTEM USING COMPUTER AIDED ENGINEERING SIMULATOR

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Abstract. Natural gas is transported to customer via gas pipeline. Any damage in the piping system will bring difficulties and even danger to public as well as the appropriate company. Therefore, the purpose of this study is to carry out stress analysis and displacement magnitude of natural gas piping system at Gas System Laboratory of University Technology Malaysia, as well as the capability of the supports to hold the whole piping system once it operated. In addition, modification of pipe supports location will be discovered in this study too. This study will focus on the stresses for natural gas piping system at Gas System Laboratory of UTM only and the piping system is designed by Gas Piping Design Group of Faculty of Chemical and Natural Resources (FKKKSA), UTM. In order to conduct this project, a Computer Aided Engineering Simulator will be used throughout this study. Only sustained loads and thermal expansion are considered in this study. The simulation results show the sum of these factors is 181.76 MPa where it is less than the allowables (241.3MPa). This performs that the design piping system is well-restrained. Modification of the supports location is done to reduce the stresses that act on the piping system. The result shows the sum of sustained loads and thermal expansion is reduced to 181.75 MPa. In conclusion, the pipe stress analysis software proposed is able to compute the stress for the piping system in this study. In addition, modification of the supports location can be considered to ensure the system is adequate for public safety once it operates.

Keywords: Natural gas piping system; stress analysis; displacement; pipe supports; computer aided engineering simulator

Abstrak. Gas asli dihantar kepada pelanggan melalui talian paip. Sebarang kerosakan pada talian paip akan menyusah dan membahayakan orang awam serta pihak berkuasa. Justeru itu, tujuan kajian ini dilakukan adalah untuk menganalisis ketegasan dan pengalihan yang berlaku pada sistem talian paip di Makmal Sistem Gas, Universiti Teknologi Malaysia. Selain itu, kebolehan penyokong paip untuk menyokong sistem talian paip turut dikaji. Kajian ini hanya fokus kepada system talian paip di Makmal Sistem Gas UTM yang mana talian paip ini adalah direka bentuk oleh Gas Piping Design Group dari FKKKSA, UTM. Bagi menjalankan analisis ini, simulasi berpandukan komputer digunakan. Antara faktor yang akan diambil kira dalam kajian ini ialah berat paip dan kandungannya, tekanan operasi serta faktor pengembangan termal. Keputusan simulasi menunjukkan jumlah ketegasan yang disebabkan oleh dua faktor ini ialah 18.76 MPa dan nilai ini adalah kurang daripada nilai yang dibenarkan (241.3MPa). Ini telah menunjukkan sistem talian paip yang direka bentuk mampu menahan ketagasan yang bertindak ke atasnya dan selamat digunakan. Bagi mengoptimumkan penggunaan penyokong paip, kedudukannya diubah suai. Hasil daripada itu, ketegasan dalam paip berjaya dikurangkan kepada 18.75 MPa. Kesimpulannya,

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ketegasan sistem talian paip boleh dinilaikan melalui pensimulasi. Selain daripada itu, pengubahsuaian kedudukan penyokong boleh dilakukan bagi memastikan keselamatan penggunaan sistem talian paip yang direka bentuk.

Kata kunci: Sistem talian piping gas asli; analisis ketegasan; pengalihan; penyokong paip; pensimulasi

1.0 INTRODUCTION

Nowadays, natural gas is widely used as an energy source in Malaysia. In fact, using natural gas as an alternative brings a lot of advantages to consumer. Natural gas is the 'cleanest' fossil fuels that produce relative fewer pollutants compared to oil and coal. Besides that, this natural resource is also a cost-effective fuel where consumer can save up to 40% of operating cost [1]. With the variety of benefits made available from natural gas, it is used in electricity generation, transportation as well as residential and industrial activities.

Processed natural gas is delivered to consumer via pipeline. From the transmission line, the gas pressure is reduced at city gate, district station and service station before it reaches to customer with appropriate pressure. City gate is the starting point of a gas distribution system. Subsequently, natural gas is sent to district station where the gas pressure is reduced to between 35 to 55 psi [1]. Meanwhile, service station is considered as a custody transfer point of gas supplied to customer. Therefore, a design of a service station is extremely important to avoid failure in supplying gas to user.

A typical mechanical design of a piping system should details piping configuration, piping support types and location, compressor cylinder bottle and piping branch [2]. From literatures, unsuitable placement and numbers of supports may cause problem to a piping system. For example, they may impose loads and the loads may exceed the allowable [3]. In another case, piping supports can influence the pipe vibration patterns. As the frequency of vibration goes above the limitation, the system will fail and maintenance activities are needed, representing cost increasing [4].

In the other hand, piping vibration is also an annoying problem which can consume unnecessary maintenance activity and can affect pumping system performance and endurance. The system includes the pipe, all piping supports, pipe to pipe interface, and machinery or devices attached to the pipe can influence the pipe vibration pattern.

Therefore, the purpose of this study is to determine the stresses and displacement magnitude for natural gas piping system at Gas System Laboratory of University Technology Malaysia. Furthermore, modification of the pipe support location is also studied to improve the overall performance of the piping system. In order to achieve the objective, stress analysis of the piping system will be carried out using Computer Aided Engineering Simulator.

The limitations of this research are:

(i) This study will focus on the stresses for natural gas piping system at Gas System Laboratory of University Technology Malaysia.
(ii) This study will consider for a carbon steel pipe which is fabricated to API 5L Class B.
(iii) The piping system is designed, fabricated, inspected and tested in accordance with ASME B31.8 gas transmission and distribution piping code.

The reasons for a pipe stress analysis to be carried out on a piping system are: to comply with legislation, to ensure the piping is well supported and does not sag or deflect under its own weight, to ensure that the deflections are well controlled when thermal and other loads are applied, to ensure that the loads and moments imposed on machinery and vessels by the thermal growth of the attached piping are not excessive, and to ensure that the stresses in the pipe work in both the cold and hot conditions are bellow the allowable [5].

According to ANSI B31.8 Gas Transmission and Distribution Piping Code, it is stated that stresses due to the sum of longitudinal pressure stress and the longitudinal bending stress due to external loads such as weight of pipe and contents, wind, etc. shall be limited to [6]:

$$S_L \leq 0.75SFT$$

where S = specified minimum yield strength, psi (kPa)
T = temperature derating factor
F = construction type factor

Meanwhile, the expansion stress range S_E shall be calculated as and limited to

$$S_E = \left(S_b^2 + 4S_1^2\right)^{1/2} \leq 0.72S$$

where S_b = resultant bending stress
= iM_b/Z, psi = $1000iM_b/Z$, kPa
S_t = torsional stress
= $M_t/(2Z)$, psi = 500 M_t/Z, kPa
M_b = resultant bending moment, in.lb (mm.N)
M_t = torsional moment, in.lb (mm.N)
Z = section modulus of pipe, in^3 (mm^3)
i = stress intensification factor
S = specified minimum yield strength, psi (kPa)

In the order hand, the sum of the expansion stress range, the longitudinal pressure stress, and the longitudinal bending stress due to preliminary loadings shall not exceed the specified minimum yield strength S [6].

Two types of loads are considered in this study: sustained loads and thermal expansion. Sustained loads are the loads caused by mechanical forces which are present throughout the normal operation of the piping system. It is including weight and pressure loading [7].

The simplest method of calculating thermal loads on supports is by using guided-cantilever method of modeling the piping system. For a guided cantilever, an imposed displacement induces the following moment and force at each end [8]:

$$M = \frac{6EI\Delta}{L^2}$$

$$P = \frac{12EI\Delta}{L^3}$$

Where P = develop force, lb (N)
M = developed moment, in.lb (mm.N)
E = modulus of elasticity at installed temperature, psi (N/mm)
I = moment of inertia of pipe, in^4 (mm^4)
Δ = imposed displacement, in (mm)
L = length of leg perpendicular to direction of growth, in (mm)

To simplify support spacing calculations, Manufacturers Standardization Society (MSS) Standard Practice SP-69 has provided recommended support spacing for various piping sizes [9]. These spans has been accepted by ASME and ANSI, has been determined by considering insulated, standard wall-thickness pipe, filled with water, limited to a maximum combined bending and shear stress of 1500 psi (10.3 N/mm^2) and maximum pipe sag of 0.1 in (2.5 mm).

Pipe support must be designed to withstand any combination of loading which is postulated to occur simultaneously. These loads may be added either algebraically to arrive at realistic values or absolutely for added conservatism, according to the design criteria requirements.

2.0 METHODOLOGY

The first step of this study is getting all relevant data to the natural gas piping system from Gas System Laboratory of University Technology Malaysia. The most important data is the isometric drawing which provides the information required to conduct this study. It is including the design codes, operating pressure, pipe supports location, pipe material, pipe length and pipe size.

Another important step in this study is verifying the sources that contribute to pipe stresses. The identified factors that create stresses for the piping system in this research can be divided into three sections which are sustained loads, occasional loads and expansion loads. The sustained loads due to weight and pressure loading that lead to mechanical forces throughout the normal operation of the piping system will be discovered in this study. The stresses that caused by thermal expansion will also are considered in this analysis. However, the effect of relief valve discharge, seismic and vibration which are classified as occasion loads are not discovered here.

The factors that have been identified for whole piping system will be analyzed by using Computer Aided Engineering Simulator-CAEPIPE. Due to the version of the software used limits 20 raw data, the whole piping system is divided into parts and analyzed from parts to parts. After that, the most critical pipe section with more components is chosen in this project for further study.

The following step is analyzing the simulation result, which included pipe displacement at X, Y, Z, XX, YY, and ZZ direction; pipe element forces in global and local coordinate; as well as the sustained load and expansion stresses.

The results of simulation are analyzed and evaluated to determine the relationship between the factors stated and stresses to the piping system. Consequently, the capability of the supports in the system is also determined during this analysis. If the supports are not capable to hold the whole system, whole system will collapse. In order to compare the results gained with permissible value, few piping codes are used as reference, such as ASME B31.8 (Gas Transmission and Distribution Piping Code) and API 617 (for compressor). For example, sustained loads and expansion stresses are compared with the allowable stresses which calculated using equation in ASME B31.8.

If the system is stable where the stresses and forces are not exceeding the allowables, conclusion and recommendation is made for this study. On the other hand, modification of the pipe support location is done to optimize the uses of pipe supports to restraint the piping system. The results of adjustment are then judged against the original results using Microsoft Excel Software.

3.0 RESULTS AND DISCUSSION

Table 3.1 shows stresses due to dead weight (SL), thermal expansion (SE) and allowable stresses that were calculated according to code B31.8 by CAEPIPE. From the table, allowable stress for sustained load is 181MPa. It is calculated by the formula 0.75ST, where the design factor is not considered here. After considering the design factor, the calculated allowable stress is 72.4MPa. Obviously, the sustained load at each node is low enough compared with the allowable. The maximum stress occurs at node 30 where this point is imposed by the maximum weight due to vertical pipe section. This shows that the weight plays a main role in contributing sustained loads to the piping system.

Figure 3.1 also shows the sustained load of the studied piping system in color-coded stress contours. Visibly, most of the stresses are imposed near the beginning section of the piping system. The maximum stress is shown in red colour. However,

Table 3.1 Pipe stresses with code compliance B31.8

Node	Code Compliance B31.8					
	Pressure Allowed (Psi)	Sustained Load, SL (MPa)	Allowable Stress, SA =0.75ST (MPa)	Expansion Stress, SE (MPa)	Allowable Stress, SA (MPa)	SE / SA (MPa)
10	50.0	3.880	181.0	0	459	0
20	50.0	9.374	181.0	0	457	0
30	50.0	18.760	181.0	0	458	0
40	50.0	9.566	181.0	0	458	0
50	50.0	1.580	181.0	0	458	0
60	5.0	4.335	181.0	0	457	0
70	5.0	0.802	181.0	0	456	0
80	5.0	4.320	181.0	0	457	0
90	5.0	1.032	181.0	0	456	0
100	5.0	5.030	181.0	0	454	0
110	5.0	2.838	181.0	0	458	0
120	5.0	1.368	181.0	0	455	0
130	0.5	2.684	181.0	0	458	0
140	0.5	1.973	181.0	0	454	0
150	0.5	0.983	181.0	0	457	0
160	0.5	0.276	181.0	0	449	0
170	0.5	1.003	181.0	0	440	0
180	0.5	1.438	181.0	0	449	0
190	0.5	0.016	181.0	0	455	0

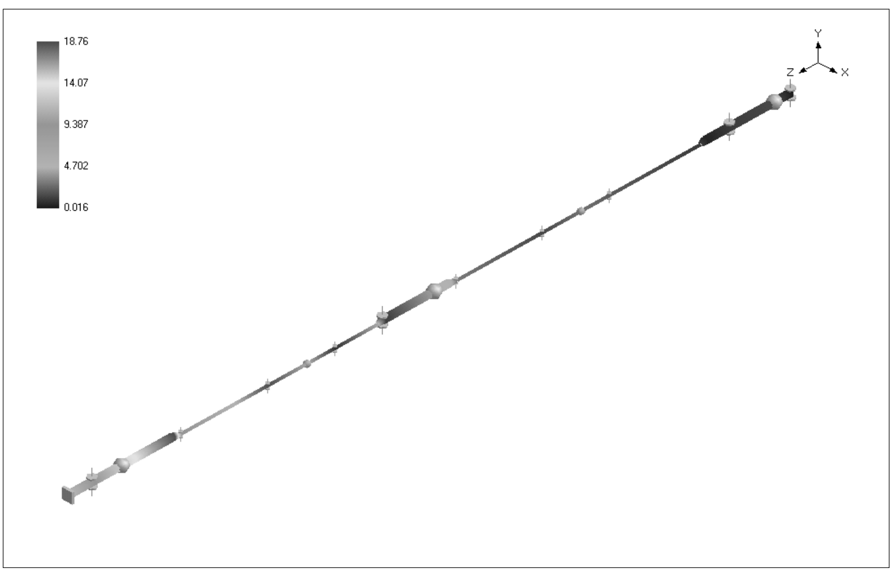

Figure 3.1 Sustained load

since the maximum stress is less than the allowable, therefore the whole piping system is considered acceptable and safe.

According to Table 3.2, the calculated expansion stress is equal to zero. The allowable stress due to thermal expansion is also calculated and compared with the actual expansion stress in term of ratio. According to the code compliance ASME B31.8, the sum of sustained loads and thermal expansion should not exceed the specified minimum yield strength (SMYS) where in this case is 35000 psi or 241.3 MPa. The study found that the summation of the sustained loads and expansion stresses that impose on the pipe is equal to 18.76 MPa. And, this value is extremely far from the SMYS of the pipe. This has proved that the designed piping system is well-restrained at appropriate operating condition and pipe material.

Figure 3.2 illustrates the displacement at X-direction. It is visibly shows that the pipe section with nominal diameter 2 inches move 0.006 mm at X-direction. From observation, it shows that this displacement is caused by the operating temperature in the piping system. Reducing of pipe diameter gradually from 4 inches to 2 inches results the increasing of pressure inside the pipe and thus it increases the operating temperature. Consequently, the pipe expands and moves as a result of sudden temperature change.

Table 3.2 Comparison of the sustained loads (SL) before and after the modification

Node	SL Before Modified (MPa)	SL After Modified (MPa)	% Difference
10	3.880	3.961	-2.09
20	9.374	9.299	0.80
30	18.760	18.750	0.05
40	9.566	9.473	0.97
50	1.580	1.554	1.65
60	4.335	4.327	0.18
70	0.802	0.788	1.75
80	4.320	4.322	-0.05
90	1.032	1.033	-0.10
100	5.030	5.029	0.02
110	2.838	2.838	0.00
120	1.368	1.367	0.07
130	2.684	2.683	0.04
140	1.973	1.975	-0.10
150	0.983	0.978	0.51
160	0.276	0.275	0.36
170	1.003	1.003	0.00
180	1.438	1.436	0.14
190	0.016	0.016	0.00

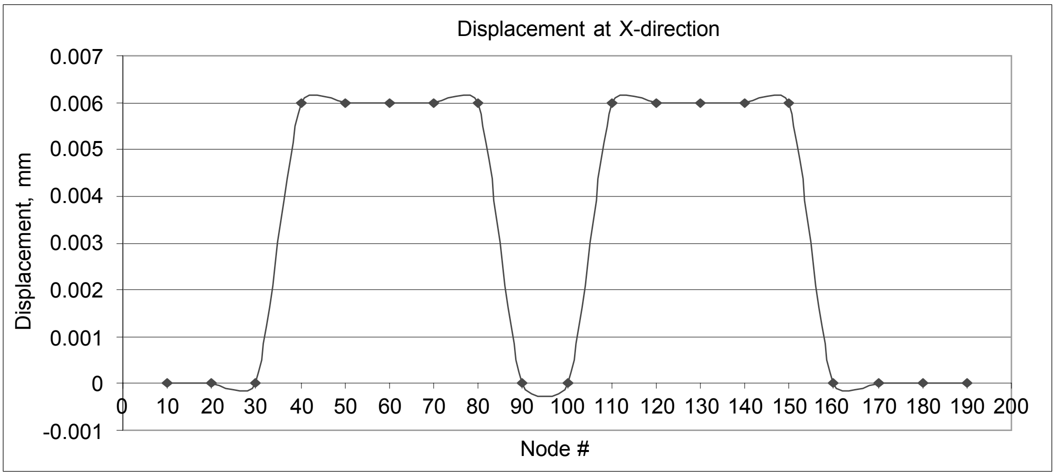

Figure 3.2 Displacement at X-axis

Another factor that influences the performance of the pipe is thermal expansion. The can be clearly seen through the displacement at Z-axis which shows linear algebraic increases. In order to enhance the capability of the pipe support to hold the whole piping system, the location of the pipe supports are modified by using CAEPIPE. This study had reduced the overall stresses and forces that act on the pipe. It found that the greatest sustained loads had been reduced from 18.76 MPa to 18.75 MPa (Table 3.3). However, modification of the pipe supports location also consequence some unpleasing increases at few points but it is tolerable and acceptable.

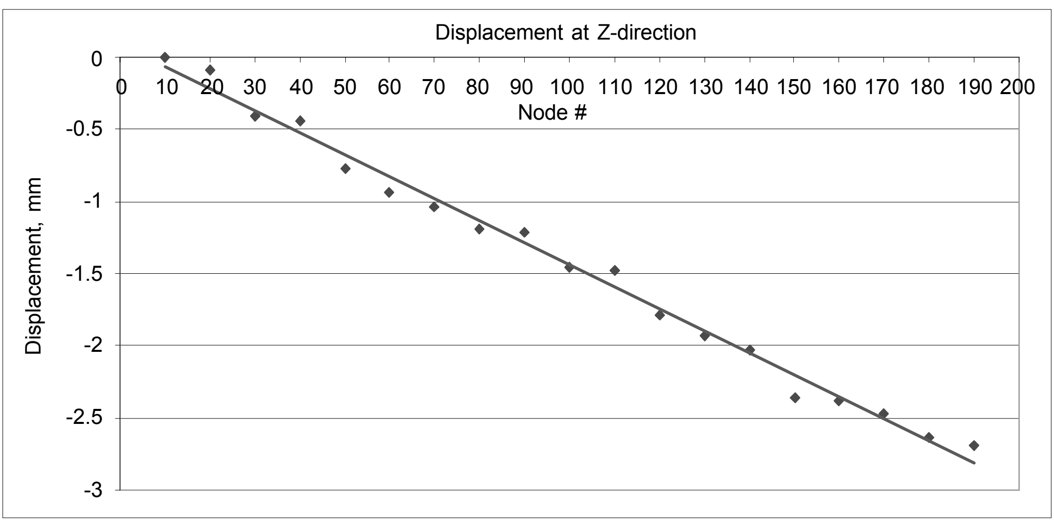

Figure 3.3 Displacement at Z-axis

Table 3.3 Comparison of the displacement at Z-direction before and after the modification

Node	Displacement at Z-direction (mm)		% Difference
	Before Modification	After Modification	
10	0.000	0.000	0.00
20	–0.093	–0.097	–4.30
30	–0.412	–0.412	0.00
40	–0.436	–0.436	0.00
50	–0.777	–0.777	0.00
60	–0.933	–0.933	0.00
70	–1.033	–1.033	0.00
80	–1.190	–1.190	0.00
90	–1.213	–1.213	0.00
100	–1.454	–1.454	0.00
110	–1.476	–1.476	0.00
120	–1.789	–1.789	0.00
130	–1.931	–1.931	0.00
140	–2.032	–2.032	0.00
150	–2.361	–2.361	0.00
160	–2.383	–2.383	0.00
170	–2.472	–2.473	–0.04
180	–2.634	–2.634	0.00
190	–2.694	–2.694	0.00

For example, the displacement at Z-axis (Node 170) is changed from 2.472 mm to 2.473 mm. Since the value is still very small, therefore these changes are acceptable.

4.0 CONCLUSION

In conclusion, the design of the natural gas piping system at Gas System Laboratory of University Technology Malaysia is adequately safe to public once it operate. This would means the piping system can withstand the stresses imposed on it due to the sustained loads and thermal expansion at operating condition. This can be proved by the sum of the sustained loads and thermal expansion (18.76 MPa) is not exceeding the allowables, 241.3 MPa.

As a conclusion, the pipe stress analysis software proposed is able to compute the stress for the piping system in this study. In addition, modification of the supports location can be considered to ensure the system is adequate for public safety once it operates.

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