DEVELOPMENT OF POLYETHYLENE GAS PIPELINE INTEGRITY ASSURANCE SYSTEM FOR FAST GROWING NATURAL GAS UTILITIES INDUSTRY IN CHINA

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Abstract
The unprecedented rate of economic growth China in the past years has called for strong demand of natural resources and energy. Natural Gas can be feedstock for chemical commodities as well as energy for a host of economic activities. Being one of the cleanest energy available locally, the use of NG is encouraged by the policy of Chinese Government. To cope with the industrialization and urbanization development, a lot of gas transmission and distribution infrastructure are being constructed all over China, particularly in those densely populated cities. Safety and integrity of these newly built NG transportation assets are no doubt the prime concern of city gas utilities companies.

For distribution network, polyethylene (PE) becomes one of the major materials used in pipeline construction worldwide. There are many advantages of PE piping system such as corrosion free, ease of installation and cost effectiveness. However, comparing with traditional metallic system like steel pipe, PE material is substantially different in term of the construction, operation and maintenance practice. The presence of PE materials in the history of gas industry in China is relatively short. The advantages of PE gas piping system experienced overseas do not necessarily guarantee the same level of success in China. The major concerns are the quality of PE pipes and fittings products, as well as the engineering and O&M management.

This paper presents a brief account of the development and implementation of a holistic quality assurance scheme of engineering and O&M management for PE gas piping system by the Hong Kong and China Gas Group. Moreover, the preliminary results of these schemes would be highlighted. Finally, the Research and Development Projects on the PE construction and inspection would also be briefed.
1 Introduction

China is one of the largest developing countries in the world. Since the late 1970s, China has attained brilliant social and economic achievements, which not only have attracted worldwide attention, and also made significant contributions to development and prosperity of the world as a whole. Such remarkable success would not be possible and sustainable without the wise use of energy and natural resources.

China is now the world's second-largest energy producer and consumer, after the United States of America. In terms of natural energy resources, China is rich in coal, limited in oil and gas. In 2007, the nation's total energy consumption was equivalent to 2.66 billion tons of standard coal. The shares of coal, oil, Hydro/nucleus/wind power and NG were 69.5%, 19.7%, 7.3% and 3.5% respectively. When comparing to the developed countries of average 23.7%, NG market in China was still at introduction stage. In the 5 years period between year 2003 to 2007, NG market in China has been growing at an annual rate of almost 20%, which is almost 2 times of that of total energy consumption. Energy is the power house of the country's economic growth and people's quality of living progress. A balanced energy consumption structure is deemed to be of utmost importance. China's coal-dominated energy structure has resulted in seriously ecological and environmental problems. China government pays great attention to improve its energy consumption structure. The increase in utilization of clean energy such as NG is on the top of the agenda of Chinese administration aiming at optimizing the energy structure for sustainable economic and social development.

Accelerating prospecting, exploration and pipeline network construction will possibly help produce more NG to meet domestic demand and even partially replace oil as a major fuel, thus greatly ensuring China's energy supply security. By 2020, the ratio of natural gas in China's total primary energy will reach 12 percent. Given such upstream supply target, it is a great challenge to downstream NG market development. Identifying consumption opportunity is never a problem to the city gas utilities, simply because of the overwhelming demand that is far beyond the supply can match with. In fact, how to satisfy the demand in the shortest possible time and perhaps the most economic way is the challenge to the city gas utilities.

In the 4 years period from 2004 to 2007, the population in China with NG supplied has increased from 56.3 million to 101.9 million, i.e. 81%, whereby more than half of the people living in cities are enjoying the benefits of using NG. The credit of such magnificent progress should to a great extent go to the wise move of the Chinese Government by inviting experienced gas industry from aboard to participate in the city gas market. Since mid 1990s, the Chinese Government has implemented an open policy to allow foreign companies to invest in city gas business. Proven gas engineering and management practices were brought into China by these foreign companies which are in turn widely adopted by local leading gas utilities. The Hong Kong and China Gas Group, also known as Towngas, is now operating over 70 city
gas joint venture companies (JV), serving approximately 10 million households and commercial and industrial undertakings. Towngas is not only one of the largest gas utilities in the Mainland; it is also the oldest energy utilities in Hong Kong founded in 1862. With public safety and asset integrity in mind, Towngas always drives for excellence by adopting advanced gas engineering technology available in market as well as in-house R&D. Towngas has over 20 years of ownership of PE pipeline and accumulated a lot of valuable experience and know-how of managing the life cycle of this asset. During the course of city gas business development, Towngas has been taking strong position in promoting PE piping system to JVs as well as counterparts in the gas industry.

The use of Polyethylene (PE) piping materials, when measured by constructed length, has been increasing recently in a way even faster than the growth of NG market. Within 4 years, the scale of NG pipeline in city area, i.e. downstream tier, has grown to more than double in length to reach 155,251km by end of 2007. As a typical example, currently under Towngas’ 70 city gas JVs in China, there is around 40,000km underground pipeline, of which 30% network length is PE pipe. In 2008 alone, out of 3,600km newly commissioned underground pipeline, the share of PE was 53%, i.e. 1,900km.

There are many advantages of PE piping system such as corrosion free, ease of installation and cost effectiveness. However, comparing with traditional metallic system like steel pipe, PE material is substantially different in term of the construction, operation and maintenance practice. The presence of PE materials in the history of gas industry in China is relatively short. The advantages of PE gas piping system experienced overseas do not necessarily guarantee the same level of success in China. The major concerns are the quality of PE pipes and fittings products, as well as the engineering and O&M management. A reliable PE pipeline integrity assurance system is definitely demanded for gas industry in China.

In view of the imminent need of NG gas pipeline integrity assurance, Towngas together with 4 leading gas utilities groups, namely Beijing Gas, Chengdu Gas, Guangzhou Gas and Shenzhen Gas, jointly established the “Gas Utilities PE Piping System Quality Assurance Alliance”, also known as “G5+” in 2008. The objective of this PE material user alliance is to elevate the PE piping system quality level of the gas industry through reinforcement of product inspection, mitigation of purchasing risk and sharing of resource between members. This alliance will leverage on its market power to influence the PE piping material players on both the supply and demand sides.

This report will elaborate the development and implementation of the PE pipeline integrity assurance system by the Towngas group and G5+ in China.
2 Objective

- This project aims at developing a PE gas pipeline integrity assurance system model for gas utilities industry in China with due consideration of the material supply chain, technical standards and asset management in the local context.
- This system must be supported by the leading gas utilities companies, gas industry association, major PE resin and material suppliers, and material testing laboratories. The system should enable the users to assure their asset integrity, while at the same time being cost effect in material procurement and construction costs; and management effort.

3 Method and Approach

Towngas opined that material purchasing standardization is the best starting point to work with alliance in the gas industry, as it addresses the most imminent issue to be resolved, i.e. material quality outside the control of gas utilities. On the other hand Towngas continues to advocate the advantages of PE piping system by establishing best practices in managing the life cycle of PE asset.

3.1 Formation of PE Material User Alliance

The China PE piping materials market expanded rapidly to cater for the demand mainly from water and gas utilities. The players along the supply chain, i.e. from PE resin to product, come from experienced companies abroad as well as new entrants from local plastic components manufacturing industry. While at the demand side, there are numerous gas and water companies, big and small. Amongst the buyers, most of them are relatively unfamiliar to PE materials; hence to a great extent heavily rely on the expertise of the suppliers who claimed to be in full compliance with National standards, to ensure the quality of PE material purchased. However, there is no guarantee of in a market that is still facing a lot of irregularity owing to fast development. Although customer should always be the king, unfortunately, there is no single company in market that is big enough to drive the market towards the quality end.

In order to consolidate bargaining power of buyers in PE material market, Towngas took the initiative to form alliance with other leading gas companies, i.e. G5+ which also put emphasis on quality of PE system and have interest in motivating major PE product suppliers to improve and ensure their PE product quality meeting with the alliance’s requirements. The alliance mutually agreed to set high standard and requirements by drafting 3 sets of guidelines as follows:

(i) Enterprise Specific PE Material Technical Standard

The existing GB standards on PE products are generally based on relevant ISO standards, but may not be updated from time to time to follow the latest revisions of ISO standards such as ISO4437:2007 for PE gas pipes. Hence it is the intention of the alliance to prepare a PE product
standard on enterprise level based on the GB standards, while also incorporating the latest requirements of ISO and EN standards as well as additional requirements that deemed necessary by the alliance.

(ii) PE Supplier Qualification
The qualification requirements and assessment criteria for potential PE product suppliers are documented. Pre and Post qualification assessments, including detailed factory audits on engineering and management processes are being conducted.

(iii) PE Quality Monitoring System
For qualified suppliers, alliance members will follow the established QA system to monitor the quality of products supplied. Such QA system includes a detailed incoming material quality inspection scheme, and sampling scheme to select samples to be tested by accredited laboratories for performance as well durability, like 80 deg C hydrostatic tests, etc. On regular basis, samples will be collected for passing to PE resin suppliers to verify the origin and composition of the PE material. Any quality issues identified will be communicated among members, and may lead to the suspension of the qualified supplier.

3.2 Establishment of PE Piping Integrity Assurance Best Practices
Towngas started to use PE gas pipe in Hong Kong in 1987, and has been using the PE pipes of sizes from 32mm to 400mm for up to 4bar applications for more than 20 years with excellent track records. Ever since the introduction of PE material, on-going engineering development and advanced technology deployment have been invested to establish a robust quality assurance system to ensure the integrity of PE gas piping asset from material procurement, design, construction, operation and maintenance, and emergency repairs. A lot of experience and expertise have also been accumulated on the use of PE material. Towngas is one of the pioneers in China to use PE pipe in gas distribution system. The proven quality assurance system practiced in Hong Kong has been transferred and adapted for use in the JV gas companies in China and to be recommended to the G5+ in future. Details of the quality assurance system are elaborated in the following sections.

a) PE pipe system code of practices
Towngas has customized a set of detailed PE system codes of practices for China construction environment, based on the ones established in Hong Kong and taking into account of the relevant Chinese national GB standards and industry standards. The codes of practices cover not only PE system but also other pipe materials like steel pipes. It addresses all aspects of gas distribution engineering comprising system design, construction, operation and maintenance and emergency handling. JVs’ engineering staffs are trained to manage and ensure all gas pipeline assets are up to the required level of integrity.

PE piping is inherently more vulnerable to impacts arising from adverse environmental and
workmanship conditions, especially during construction stage. For example particular emphasis has been put in procedures detailing in-situ material storage and handling against UV and contamination; trench preparation against pipe/coupler misalignment and pipe jointing workmanship and equipments.

**b) PE pipes, fittings and valves**

All PE materials used must meet the relevant national and international standards as an entry criterion. Towngas imposes additional specification requirements when necessary to supplement these standards. For example, Towngas tightens the requirements on the dimension of internal bore of PE couplers, rather than simply follows individual supplier’s own specification. From site experience and failure case analysis, in order to assure a quality joint with due allowance for in-situ workmanship and alignment uncertainty, the control of the clearance between PE pipe and coupler within a desirable range is important. After numerous field trials and tests, Towngas has formulated a table of coupler internal bore dimension and fusion zone length requirement for product selection. Such requirement has been communicated to suppliers for their product development.

Suppliers need to provide evidence that their products have completed the necessary type tests according to the standards by accredited third party laboratories recognized by Towngas. Every batch of PE materials delivered to Towngas and JVs need to be supplied with conformity certificates and batch release test reports meeting the standards.

Towngas identifies a list of qualified PE product suppliers, and the JVs should generally purchase PE products from the list of qualified suppliers. To be listed, potential suppliers will be critically assessed in terms of capability, technical competency, quality assurance, and service support. Their factories will be audited by a team of competent auditors to affirm the suppliers meeting with the Towngas requirements. The suppliers need to be certified to ISO9001 quality assurance system standard, and should have in-house qualified laboratory with the necessary QC equipment to do all the essential type tests and batch release tests.

All the PE products must be made from PE80 or PE100 compounds. Only the use of PE natural and master-batch is allowed for making PE products. Since the quality of PE products very much depends on the quality of the PE compounds used, Towngas critically assesses the PE compounds available in the market, and shortlist those of proven quality in a list of qualified list of PE80 and PE100 compounds. PE products supplier shall strictly adhere to the requirement of using PE compounds in the qualified list. Towngas also specifies the use of 100% virgin PE materials, and no reused materials are allowed to be mixed in the production of PE products.
Upon receiving PE products supplied from qualified suppliers, JVs will conduct incoming material quality check (IQC) including visual, dimensional and simple mechanical inspections under a pre-defined sampling plan. Further samples will also be selected for passing to qualified laboratories to conduct material physical tests to confirm the quality of the products. Moreover, samples will also be selected for sending to the PE compound supplier to verify if the product PE material is their material.

c) PE jointers
At the end of PE material supply chain, installation is the final and most critical point before the PE piping is turning into operating asset of the company. Good workmanship in the PE pipe installation and especially jointing is another key success factor to ensure the integrity of the PE system installed. Towngas has been providing structured training to PE jointer shortly after the introduction of PE piping system in Hong Kong in the late 80’s. A qualified PE jointer system was implemented, whereby only trained PE jointers, both direct and contractors’ workforce, are allowed to work on any PE piping installation. The qualification system was further upgraded in 1996 to include an annual revalidation test for all trained PE jointers to upkeep their skills level. Besides training facilities in Hong Kong, Towngas has her own training institute in Shangdong province in China which provides PE jointer training courses to JVs’ workforces. PE jointers need to complete a comprehensive training course which includes the basics of PE materials, PE jointing both in electro-fusion and butt-fusion, and general PE pipe installation technique covering both theoretical and practical aspects. Written and practical examinations are compulsory for becoming a qualified PE jointer. The qualified jointers need to be revalidated every year through making PE joints which should be able to pass stringent destructive tests. The training scheme and assessment criteria in China are basically replicated from the model of Hong Kong which has been in full implementation since 2006.

In Hong Kong, competence of PE jointers is further assured by a mentor programme for the freshman. After completing training, fresh jointers are put in a mentor programme for a probation period. An experienced jointer is assigned as the mentor or baby-sitter monitoring the freshman for making the first 50 joints. Amongst these completed joints, joints will be cut out by sampling for NDT.

d) Equipment
Traditional mechanical piping jointing methods, such as bolt and nuts, screw threading, etc., can be made perfect by using appropriate tools like torque wrench. After passing soundness test with pressure there is not that much of uncertainty of latent defects in the joints. While for fusion type joints of steel pipes by electric arc welding, besides pressure test, there is also
non-destructive test (NDT) such as X-ray to double check the joint integrity. However, there is still no proven and cost effective NDT method which could verify the PE joint quality in an efficient manner and high degree of confidence. It is very important to make joints strictly in accordance with standard jointing procedures. Although jointers are well-trained, human errors should still be minimized to the best extent, where jointing equipments play an irreplaceable role.

Butt-fusion joints are very common especially for joining larger diameter pipes. Also failures of butt fusion joints are typically full bore leading to abrupt gas escape which induces great risk to human life and properties in the vicinity. To mitigate such risk due to human errors in making butt fusion joints, Towngas mandate the use of fully automatic butt-fusion machines complying to relevant standards and with proven operating control parameters. All joints records are downloaded to the computer for storage and traceability. It also requires removing the external beads of all butt fusion joints for quick quality checks. The beads are inspected for any contamination and bended backwards to verify if there are any slit defects. Joints with any defect found will be cut away for rework. Similarly, for electro-fusion jointing, the electro-fusion control units typically used by Towngas Groups of company are fully automatic with barcode reading capability as well as fusion process data logging for computer record storage and traceability. Last but not the least, all fusion jointing machines, including those in the custody of contractors, needed to be calibrated regularly to ensure their accuracy and working condition.

Auxiliary equipments and tools working conditions, such as scraping tools and pipe clamps, are part of quality and installation process control check items.

e) Technical Audit

Quality of works does not come in being naturally with all the above measures in place. Towngas also conducts technical audit on in-process quality control. An independent Quality Assurance unit is established to monitor construction of PE piping system. The prime focuses are: jointers competence and qualification, equipments, material handling, traceability and working procedures in site. There is also a project basis sampling plan, depending on length and size of piping, to cut out completed joints for NDT. A marking scheme is developed to record assessment results and from which performance bench-marking report is generated for management monitoring. Technical audit has been implemented since 2007 in Hong Kong and is being trial run in selected JVs in China.

f) GB and industry standards for PE system

In China, gas industry is administered under the jurisdiction of various government departments in different administrative arms, just to name a few, construction, quality supervisory, labour and
gas office. The PE material manufacturing industry falls under the administration of Light Industry Bureau. There is specialist committee commissioned by the bureau for drafting National Standards (GB) and Industry Standards (CJJ). With a vision to promote PE material for the betterment of the gas industry, it has been a strategy of Towngas to influence the drafting and implementation of these technical standards. Towngas and its associated companies in China actively participate in the preparation and revision of GB and industry standards related to PE gas system products and codes of practices. The standards, which Towngas has involved, include the GB standards for PE gas fittings, electro-fusion control unit, butt-fusion machines, and PE transition fittings. Expert advice on GB Standards for testing methods like peel test, crush test and electro-fusion jointing assembly; and CJJ Standards on PE system construction, and national PE jointer scheme were also contributed by Towngas. Towngas’ PE material manufacturing JV GH-Fusion is also leading a drafting committee in preparing a GB standard for butt-fusion jointing standard based on ISO21307 standard.

4 Results and Progress

4.1 Formation of PE Materials User Alliance
PE Materials User Alliance was formed in March 2008 with members of gas utilities, including 5 leading gas utilities: Beijing Gas, The Hong Kong and China Gas (Towngas), Chengdu Gas, Guangzhou Gas and Shenzhen Gas. The alliance has commissioned a team of experts in PE material to prepare 3 sets of guidelines which were endorsed in June 2009. Firstly, the alliance will trial-run the system on PE pipe purchasing in the second half of 2009.

4.2 PE Pipe Supplier Quality Assurance Programme
Towngas is implementing a programme of deploying its inspectors at suppliers’ factories to monitor product quality during production. The inspectors will ensure that the designated PE compounds are used and the production and QC are in line with the alliance’s PE product standard. Also all the required batch release tests are completed before delivery to the customers. The programme has been in place for over 2 years and significant improvement in quality control of PE products is achieved.

4.3 Technical Audit Programme in Hong Kong
Since 2007, an independent Quality Assurance unit has been set up in Hong Kong for monitoring the construction of PE system by conducting extensive technical audits. During the audits, critical items of codes of practice would be check against and Performance Index is defined to record the results. Also, all the results have been stored for analysis and performance monitoring.
In order to facilitate the statistical analysis, the audited items are divided into 4 main categories, which are briefed as follows:

<table>
<thead>
<tr>
<th>Quality Aspects</th>
<th>Items involved</th>
</tr>
</thead>
</table>
| Material        | √ PE pipe and fittings should be covered to avoid prolong exposure of sunlight  
                 | √ E/F fittings should be stored and protected from rain/water and other contamination |
| Pipe laying     | √ Jointers competence  
                 | √ Proper scraping of PE pipe  
                 | √ Proper use of alignment clamps  
                 | √ Laying of detectable warning tape and protection tile  
                 | √ Equipment calibration |
| Site Safety     | √ Trench Support and safe mean of entrance and exit  
                 | √ Proper and adequate fencing to secure public safety  
                 | √ Personal Protective Equipments |
| Others          | √ Valid excavation permit |

According to the results of more than 750 technical audits, a 6-Months Simple Moving Average of Performance Index is presented as below:
In the above graph, smaller value of index represents better performance. The overall Index is on decreasing trend showing that quality is generally improving and the aforementioned quality assurance system is effective.

### 4.4 Technical Audit Programme in China

In order to standardize the PE quality, a set of procedures have been developed to cover the asset life cycle of PE pipeline. Key items are tabulated as follows:

<table>
<thead>
<tr>
<th>Asset Life Cycle</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>✓ MOP of PE pipeline&lt;br&gt; ✓ Proximity with building and other utilities&lt;br&gt; ✓ Location of isolation valve</td>
</tr>
<tr>
<td>Procurement</td>
<td>✓ Approved suppliers list&lt;br&gt; ✓ Recommended the centralized procurement&lt;br&gt; ✓ Limited the use of butt-fused fittings</td>
</tr>
<tr>
<td>Construction</td>
<td>✓ Proper PE material storage at site&lt;br&gt; ✓ Recommended the application of fully automatic fusion machine&lt;br&gt; ✓ Promote the use of alignment clamp&lt;br&gt; ✓ Competency and assessment of jointer&lt;br&gt; ✓ Inspection of fusion joints</td>
</tr>
<tr>
<td>Testing &amp; Commissioning</td>
<td>✓ Pressure testing&lt;br&gt; ✓ Pigging of newly constructed PE pipeline</td>
</tr>
<tr>
<td>Operation &amp; Maintenance</td>
<td>✓ Emergency handling&lt;br&gt; ✓ Live gas connection&lt;br&gt; ✓ Leakage survey</td>
</tr>
</tbody>
</table>

The results of trial-run conducted in the 1\textsuperscript{st} quarter of 2009 were found effective:

<table>
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<tr>
<th>Quality Aspect</th>
<th>After</th>
<th>Before</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Package of fitting

Use of roller

Control of Fusion time

.overflow of molten PE due to the excess fusion time

Cleaning of pipe before scrapping
For measuring the effectiveness of the system as well as the bench marking for JVs, a performance report system was prepared and put in pilot-run in selected JVs commenced in second half of 2009. The performance report system included the following major categories:

- Material management
- Construction practice
- Welding procedure
- Destructive test
- Equipment calibration
5 Conclusions

This PE Gas Pipeline Integrity Assurance System enables gas utilities to enjoy the technical and economical benefit of PE piping while at the same time mitigating potential quality deficiencies in PE materials by means of well-defined buyers-sellers quality requirement protocol. With this system, gas utilities can assure their gas transportation infrastructures satisfying the fast growing demand for clean energy – Natural gas and safety for the public at large.

The Hong Kong and China Gas (Towngas) is a forerunner in China in the application of PE piping technology. Specialist teams in Towngas have successfully consolidated the know-how in technologies and asset management system proven in local environment; together with worldwide best practices into a PE Gas Pipeline Integrity Assurance System that contributes to the gas industry in China.