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Grading evaluation of non-API OCTG quality level based on working conditions

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Abstract. The non-API standard series of oil country tubular goods (OCTG) have been developed rapidly to meet the increasing demand of the oil and gas fields, while the frequent accidents of non-API OCTG still occur due to the lack of a perfect quality management system. In this paper, the main types, service conditions, and the current status of quality evaluation technology of non-API OCTG at home and abroad were introduced. For the quality problems of non-API OCTG during the domestic application, the needs of the industry development needs and continuous improvement of quality management system were taken into consideration. Based on the working conditions, the quantitative evaluation method of quality grading was built by the grading idea represented by capability maturity model integration (CMMI) based on the field working conditions. And an evaluation method, including process maturity level, items, indexes and procedures, was proposed and verified. The results showed that the average value and level of quantitative evaluation results of quality grading were 81.5 and C, respectively, which was in good accordance with the current status of non-API product management. The evaluation method is more quantitative and targeted, which would provide for the completeness of the non-API product quality management system with methodological support and theoretical reference.

Keywords: Non-API OCTG / quality classification / evaluation / quality management system

1 Introduction

According to the US Department of Energy (DOE) statistics, the depth of oil and gas wells in the world has been doubled since the 1980s, and continously grown [1]. With the increase of well depth, temperature and pressure, the Oil Country Tubular Goods (OCTG) is faced with many new problems, such as corrosion and fracture [2–6]. From the development trend, the quality, variety, and service performance of OCTG have restricted the progress of the petroleum industry to a certain extent. However, in the face of increasingly harsh environments for oil and gas development, API OCTG is difficult to meet its exploitation needs.

Therefore, research and development of non-API standard OCTG are a significant trend in the development of the petroleum industry [7,8]. From the initial development to the current growth of the non-API series of OCTG, the number of the product types has increased to more than 300. About 40% of OCTG has been actually used [9]. And the usage ratio of OCTG with particular screw joints is close to 25% and is still expanding [10]. As more and more non-API standard series products are used in oil and gas development, many problems have been present in practical applications, such as casing rupture and spalling OCTG by particle erosion [11–14]. One of the reasons is that the development of OCTG in China started late. Until the 1980s, China still did not have a set of OCTG standard system, which seriously restricted the development and use of high-end OCTG products in China. Another view is that China's metallurgical quality level is limited. However, the deeper reason is the lack of unified industry standards, a sound service monitoring means and from design, supervision to service of the whole process of OCTG quality management system. Thus, the systematic management of non-API product quality has become one of the important research topics in the oil and gas fields.

In view of the problems faced by quality system management of non-API OCTG, the quantitative evaluation method of non-API OCTG quality grading was built in this paper, in which the existing related technical resources were integrated, and the CMMI Capability Maturity Evaluation Model was adopted [15–17]. Based on the needs of industry development and the continuous improvement of quality management system, the quantitative evaluation method of non-API OCTG quality classification is studied.

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The evaluation methods such as process maturity level, evaluation project, evaluation index and evaluation procedure are proposed. Compared with the general evaluation method, it is more quantitative and targeted, in order to provide reference for the non-API product quality management system.

2 Generation and development of NON-API OCTG

OCTG includes two categories: API OCTG and non-API OCTG. API OCTG is a class of OCTG produced and inspected according to API standards, which has the characteristics of mature technology and robust versatility. While non-API OCTG refers to a class of OCTG entirely or partially produced by non-API standards, which is a more versatile product to meet certain special functions according to the needs of oilfield operations, and is an independent product belonging to each manufacturer.

Non-API OCTG is divided into three categories according to their usage performance: the non-API steel grade series (Class 1), having high resistance to extrusion, high strength, and excellent corrosion resistance compared with API tubing the particular thread series (Class 2), mainly used in deep wells, ultra-deep wells, high-pressure gas wells, and other harsh oil and gas well conditions, and the special function series (Class 3), with geometric dimensions of tubing, such as the outer diameter, wall thickness and joint size. The commonly used term non-API OCTG mainly refer to Classes 1 and 2. Moreover, non-API steel grade OCTG is also used with special threads in most cases, and Non-API OCTG is actually API OCTG with high or exceptional performance.

2.1 Particular steel grade series

More than 110 non-API steel grades have been available in China, which has been developed to a much greater extent than that API steel grade types [18]. Non-API drill pipes also include various species, such as ultra-high-strength drill pipes, high toughness drill pipes, drill pillar structural parts for the robust acidic environment, high torsion joint drill pillar components, and drill pillar components for the low-temperature setting, and intelligent drill pipes, etc. Non-API OCTG has played an essential role in developing the oil and gas fields in western China, and the ratio of the practical applications of non-API OCTG in the Tarim oil field has reached 60% [19].

Tables 1 and 2 show the main particular steel grade of non-API tubing and casing at home and abroad. There are more famous foreign particular steel grade casing, such as the VM series from V&M, SM series from Sumitomo, NK series from NKK, NT series from Nippon Steel, and KO series from Kawasaki, etc. And the domestic particular steels include TP series from Tianjin Pipe Corporation, BG series from Shanghai BaoGang, and CS series from Pancheng Gang [20].

More than 10 product series of tubing and casing of non-API exceptional steel grades at home and abroad have been formed for different usages, such as deep wells, high and ultra-high extrusion, hydrogen sulfide stress corrosion, both H_2S corrosion and high extrusion, CO_2 corrosion, and $H_2S + CO_2 + Cl^-$ environment [21]. The technical level of non-API steel grade domestic products is generally close to that of similar products at abroad. However, there is still an individual difference in the technological field of high-end OCTG [22–23].

2.2 Particular thread series

Casings are used to support the well wall and ensure the regular operation of the entire well during drilling and after completion, which is assembled by threaded fittings, the casing column is generally subjected to internal pressure, external extrusion pressure, and tensile load from gravity in the well, and the threaded connection is the most vulnerable part of the casing column. According to statistics, about 90% casing failures occur at the threaded connection [24,25], and about 64% casing failures happen at the threaded connection in foreign and 86% at home [26].

Early 20th century, the production of API round threads led to the widespread use. By the 1940s, the API bias trapezoidal thread was born. However, with the increasingly demanding environment of the oil and gas extraction, API threads cannot meet the needs of the oil industry, so the development of special threads with high connection strength and good sealing performance became a new challenge for the domestic and foreign companies [27]. At present, more than 200 threaded joints have been developed and researched at home and abroad, as shown in Tables 1 and 2, [28,29], and about 40–50 kinds of particular threaded joints have been used in the oil and gas fields in China.

3 Status of non-API OCTG quality evaluation technology

The quality evaluation of non-API OCTG covers the whole process of design and selection, manufacturing, inspection and testing, protection, service maintenance, and product failure analysis of the non-API products. As the demand for non-API OCTG products increases, the higher requirements for quality control of non-API OCTG have been put forward. At present, the problems existing in the quality evaluation of non-API OCTG are as follows [30]:
no relevant inspection and supervision institution;
– lack of standardized field verification index;
– lack of systematic applicability evaluation system;
– lack of product quality evaluation system.

Among them, scattered standards, missing system, and imperfect technical requirements are the most prominent. Therefore, it is impossible to conduct a comprehensive evaluation of the service quality of non-API OCTG from design production to users in the whole processes, and the integrity cannot be guaranteed.

3.1 Scattered industry standards

In recent years, the oil and gas development conditions have been increasingly complex and harsh, especially the environmental conditions of 10,000 meters ultra-deep

Table 1. Major foreign non-API oil casing plants and major products.

Country	Factory	Main special steel grades	Main special threads
Germany	V&M	VM-140~155, VM-55LT~125LT, VM80HC~140HC, VM-80SS~125SS, VM-90HCS, VM-95HCS, VM-80-HCSS-110HCSS, VM28, VM825, VMC3, VM50	VAM HP, VAM MUST, VAM HW, VAM TM, VAM TOP, VAM FJL, VAM ACE, NEW VAM
	Sumitomo Metals	SM-55LT~110L, SM-110LL, SM-140G~G, SM-80T~110T, SM-95TT~125TT, SM-80SS~110S, SM-95TS, SM13CR-80~95, SM13CRS-80~110, SM13CRM-80~110, SM22CR-65~140 SM25CR-75~140, SM25CRW-80~140	VAM Series(VAM, NEW VAM, TM, VAM ACE, VAM TOP)
Japan	Nippon Steel		NSCC, NSCT, BDS, TDS
	NKK	NK-140, NKV-150, NKCT-110~125, NKHC-125, NKHC-140, NKAC-110SS,	NK3SB, NK2SC, NKEL, NKSL
	Kawasaki	KO-13Cr80~13Cr110, KO-HP1-13Cr95, KO-HP1-13Cr110(~180°C), KO-HP2-13Cr95, KO-HP2-13Cr110	FOX, BEAR
USA	Hunting	Main special threads of Hunting SEAL-LOCK CONNECTION (APEX, BOSS, FLUSH, HC, HT, SF, XP) TWO-STEP CONNECTION (TS-HD, TH-HD-SR, TS-HP, TS-HP-SR) TKC CONNECTION (TKC Convertible BTC, TKC Convertible EUE, TKC Convertible LTC, TKC MMS LTC, TKC BTC and Plus, TKC FJ-150)	
	Hydril	Hydril SLX, Hydril MAC-11	
Italy, Argentina, Japan, etc.	Tenaris	Main special threads of Hunting TenarisBlue, TenarisBlue Near Flush, TenarisBlue SAGD, AB TCH, AB RTS, AB ST-L, Tenaris 3SB, Tenaris MS, Tenaris ER, Tenaris PJD	

Table 2. Major domestic non-API oil casing plants and major products.

Number	Factory	Main special steel grades	Main special threads
1	Tianjin Pipe Corporation	TP80~125S,TP80~110SS, TP95~100TS, TP80~125H, TP80~125T, TP110~125TT TP140V, 155V, 170V, 3Cr, 13Cr	TP-CQ, TP-JC, TP-NF, TP-G2, TP-G3, TP-EX, TP-TS
2	Shanghai BaoGang	BG80~125S, BG80~110S, BG95~110TS, BG80~110H BG80~140T, BG110~140TT, BG140~150, 3Cr, 13Cr, BG2830, BG2250	BGC, BGT, BGT1, BGT2
3	Pancheng Gang	CS-80~110S, CS-80~110SS, CS-80~110TS, CS-90~120H, CS-80~110T, CS-80~110TT, CS-140, 3Cr, 13Cr	FOX, Bear, CST

wells, including complicated mechanical, high temperature, high pressure, high strength corrosion, special structures, and special technology. The applicability of existing OCTG standards needs to be further evaluated in combination with specific working conditions, the theoretical and technical issues supporting the development and revision of measures need to be further developed, and the standard system needs to be further improved.

Non-API OCTG is customized chiefly designed and manufactured for different oil and gas exploitation conditions, while the product technical specifications/order technical agreements vary significantly among manufacturers/users due to additional performance index requirements. At present, there are more than 30 national and industry standards for non-API OCTG, but the related standards for the same product are uneven. Some standards are not systematic, them are not revised in time, the quality level is not high, the publicity and implementation is not in place, and the international standards are not revised enough [31–34], including product specification, design verification, inspection test, selection, grading, and evaluation methods, etc. In addition, the production plants have drafted their product standard specifications, and each oil company has also the corporate standards. The Chinese Society for Testing & Materials (CSTM) is developing the relevant group standards in recent years. It is impossible to comprehensively assess the service quality of non-API products for the standard dispersal system among production plants, users, and research institutes in the whole process.

The diversification and complexity of non-API OCTG standards have placed higher demands on implementing industry standards. In the quality control of OCTG, if the relevant standards are not unified, the involved products do not meet oilfield production needs. The products will fail in service, resulting in corresponding economic losses to the oilfield and the industry. The imperfect quality evaluation technology of non-API OCTG, the lack of unified national (or drive) product standards, and the acceptance specifications of non-API OCTG products are the main factors that restrict the high-quality development of the non-API OCTG manufacturing industry.

3.2 Single means of on-site monitoring and surveillance

During the drilling, completion, and production processes, the destabilization of the drill column and oil casing column is caused by external forces or corrosion damage, which significantly affects the safe production of the oil and gas fields. Therefore, the service status of the pipe column need to be often probed by on-site inspection or online monitoring, while the indoor evaluation is mainly focused on at present.

Oilfield monitoring is an essential early warning measure for oilfield safety production. Various monitoring technologies are widely applied to assess the corrosion risk of crucial equipment and pipelines. Monitoring technologies have become an essential safeguard for oilfield production. Among the existing monitoring techniques for downhole tubular column field inspection and corrosion, ultrasonic, hydrogen permeation, and other non-destructive testing techniques are inefficient that cannot achieve real-time monitoring [35]. Such as downhole corrosion hanging inspection techniques can apply for oil casing corrosion detection but not for continuous corrosion detection [36]. Resistance probes for broad applications, but erroneous data will be obtained when deposition of probes occurs due to its resistance is measured by corrosion-induced cross-sectional changes. Electrochemical probes have the advantage of fast response but require a strong conductivity of the measured medium. Inductive probes apply to get corrosion data by measuring the inductance changes in inductance caused by the corrosion of metals, which has good accuracy and stability. But there is still a lack of real-time monitoring technology for the corrosion rate of the oil pipeline in the downhole oil field environment [37–39].

Therefore, for the quality control of non-API OCTG, the inspection means for oil field sites have certain limitations, which cannot meet the efficient and convenient modern drilling and production needs.

3.3 Lack of quality evaluation system

The essence of non-API OCTG quality control is to fully guarantee the whole process of tubing products from design, third-party supervision and manufacture to oilfield service.

It includes the correct selection of product standards for the applicable level, the formulation of supplementary technical conditions for ordering, the strengthening of third-party on-site supervision of purchased products, the on-site inspection of products and the real-time monitoring of service. An efficient and applicable quality evaluation work of non-API OCTG can systematically reflect the business level of the manufacturing company, the professional capability of the third-party inspection agency, and the effectiveness of quality control at the oilfield site.

For the quality evaluation of non-API OCTG, it can be understood as a third testing institution with qualifications or universal credibility.

4 Quality grading quantitative evaluation method

To better deal with the failure of non-API OCTG in service, based on the grading idea represented by CMMI (Capability Maturity Model Integration) a set of quantitative evaluation methods for quality grading was proposed, and there are four phases of the specific implementation.

4.1 Process maturity level classification

The quality management system is composed of one process after another. Therefore, to quantitatively evaluate the operation of the quality management system, it is necessary to take each process that makes up the quality management system as the entry point. In this paper, each function of the quality management system has five maturity levels, with level A being the lowest and level E being the highest, and each evaluated object initially defaults to level A. An example of maturity level classification is shown in Table 3.

4.2 Identify process evaluation items

After determining the maturity level classification of each process, the specific evaluation items (i.e., scoring items) for each process need to be determined, which come from the requirements in the company's quality grading system document. Moreover, there are some differences in the degree of requirements for non-API OCTG from different companies. At the same time, the evaluation items were tailored to differentiate different maturity levels of the same process. For example, the typical maturity level evaluation items for non-API tubing quality issues are shown in Table 4.

4.3 Development of process evaluation indicators

According to the process evaluation items, the compliance degree of each evaluation item in two dimensions, "Attainment" and "Extent," is evaluated. Among them, "Attainment" means "meets the requirements" or "does not meet the requirements," and is indicated by "0" and "1," respectively. And "Extent" reflects the "level of doing," and five levels ("1", "0.9", "0.8", "0.6" and "0.3") are listed.

Table 3. Example of quality grading process maturity levels.

Grade	Maturity characteristics
Level A	The evaluation technology of pipe selection is not perfect, and there are great defects in the design of pipe composition; Poor control of manufacturing process and lax supervision of key indicators; Lack of inspection and monitoring means; No design, manufacturing and service monitoring specifications have been formed; Inadequate understanding of service conditions and pipe applicability for non-API products; No API series product quality control standards; Non-API oil well pipe series products with various requirements are not managed, and most of them are not systematically evaluated.
Level B	with mature pipe composition design and manufacturing process; Single means of inspection and testing, and no recognized benchmarks; No design, manufacturing and service monitoring specifications developed; For the staff of the non-API product service conditions and pipe applicability awareness training, employees have a certain understanding of the relevant requirements; A small number of non-API tubing products were systematically evaluated, there are still a majority of cases not evaluated; No product development evaluation and site acceptance evaluation; A small number of unexpected uses of non-API products; No requirements for non-API series product quality control standards.
Level C	Formed design, manufacturing and service monitoring norms, but the relevant norms scattered, can not form a unified user, research institutes and factories; Single means of inspection and testing, but with recognized benchmarks; The practitioners have a good understanding of the applicability of non-API series working conditions and pipes; training process with proven knowledge of service conditions and tubing suitability for non-API products; Forming non-API series product specifications, and in line with relevant regulations and requirements; Product development appraisal and on-site acceptance basis; No or little unexpected use of non-API products is detected; Requirements for formulating relevant non-API series product quality control standards.
Level D	Forming a normative unity between users, research institutes and factories; Form a multi-mode inspection and testing means with recognized benchmarks; A training system with a mature understanding of the service conditions and pipe applicability of non-API series products; Non-API tubing products are standardized and comply with relevant regulations and requirements; Product development appraisal and on-site acceptance basis; No or little unexpected use of non-API products is detected; All non-API standards and their changes have been included and recognized by the industry, but there is no uniform standard; Research and rectification of the use of oil fields, the measures taken are effective.
Level E	All industry certification, series standards and evaluations have been standardized and can be easily used, and a unified standard has been formed; In-depth understanding of the issues returned and the ability to refer back to them; Some degree of qualitative analysis of the overall maturity process implementation; Conducted qualitative and quantitative analysis of non-API well tubing quality conditions, proactively identifying problems and taking effective corrective action and preventive measures; The management of this quality grading work is standardized and efficient and can be constantly updated and recognized by the industry.

4.4 Evaluation procedure

The above three steps have established a quantitative evaluation system with the standard quality grading system as the core. When needed, each industry implements a quantitative evaluation of the quality grading system operation. Specific evaluation procedures are as follows [40].

First, the relevant literature, records, and standards were reviewed. The implementation of each quality management system process in terms of “Attainment” and “Extent” was evaluated separately.

If an evaluation item is inconsistent or provides invalid data during the inspection, then “Attainment” is “0”, otherwise, it is “1”.

Table 4. Example of quality grading process evaluation items.

Number	Evaluation items	Level
1	Is there a mature pipe composition design and manufacturing process ?	
2	Is a design, manufacturing and service monitoring specification formed ?	
3	Is the inspection and testing method single, and is there a recognized inspection measurement benchmark ?	
4	Is a design, manufacturing and service monitoring specification formed ?	
5	Whether to train the staff on the working conditions and the applicability of the pipe, and whether the staff understand the relevant requirements of the non-API series ?	Level B/Level C
6	Do non-API products have product quality certification ?	
7	Are non-API series product specifications formed and comply with relevant regulations and requirements ?	
8	Is there an unexpected use ?	
9	Are there requirements for non-API series product quality control standards ?	
10	Are the relevant requirements of non-API series product quality control standards formulated and industry unified ?	
11	Is there industry product quality supervision and supervision ? Is there an industry administrative license, manufacturing license ? Are there uniform product standards and acceptance specifications ?	
12	Does the problem from the on-site response complete the rectification and whether the measures used are effective ?	Level D
13	Is the development of technical oil well pipe for special requirements locked in its corresponding oilfield ?	
14	Do the established non-API standards still meet the requirements and are the standards easy to apply ?	
15	Are all labels and specifications unified ?	
16	Is it sufficient to draw inferences about the problem of oilfield feedback ?	
17	Does the company have a record of the manufacture, field use and recycling of their non-API tubing ? Is the record complete ?	Level E
18	Is the entire implementation process analyzed, and is the analysis adequate?	
19	Is it effective to identify the problems found in the whole implementation process and take relevant improvement measures ?	

As for the “Extent” for each evaluation item, the provided data is first judged as “valid.” If discrepancies are not noted during the inspection, it is “1”, “0.9” for one, “0.8” for two, “0.6” for three, and “0.3" for four or more [41]. The score of each process (Q_n) can be obtained according to equation (1).

$$Q_n = \frac{\sum_1^s D_k \times C_k}{s} \times 100(k = 1, \ldots, s), \tag{1}$$

where D_k is the “Attainment" value of each evaluation item of the process, C_k is the “Extent" value of each evaluation item of the process, and s is the number of evaluation items.

Secondly, based on the calculation of each process score, the quality grading system operation (Q) score can be calculated—by calculation Formula (2).

$$Q = \frac{\sum_1^m Q_n}{m}(n = 1, \ldots, m), \tag{2}$$

where m is the number of processes included in the enterprise quality management system.

Thirdly, the maturity level of each process is determined based on each process score. The maturity level of the entire organization is the lowest maturity level of all functions. The specific criteria for determining the process maturity level are shown in Table 5.

5 Implementation

According to the above evaluation processes, the graded quantitative evaluation of the conventional non-API quality management system was carried out, and the specific implementation processes follow in Figure 1.

Taking the quantitative evaluation of the “Usage Standards" process as an example, the process items are determined according to the Delphi method [42], and the implementation process is as follows.

Table 5. Quality grading system process maturity level determination guidelines.

Grade	Judgment criteria
Level 1	$Q_n < 70$ (only the evaluation items of grade C and below are calculated)
Level 2	$70 \leq Q_n < 80$ (only calculate C level and below evaluation items)
Level 3	$80 \leq Q_n < 90$ (only calculate C level and below evaluation items)
Level 4	$90 \leq Q_n < 95$ (only calculate C level and below evaluation items)
Level 5	$95 \leq Q_n < 100$ (calculate all evaluation items)

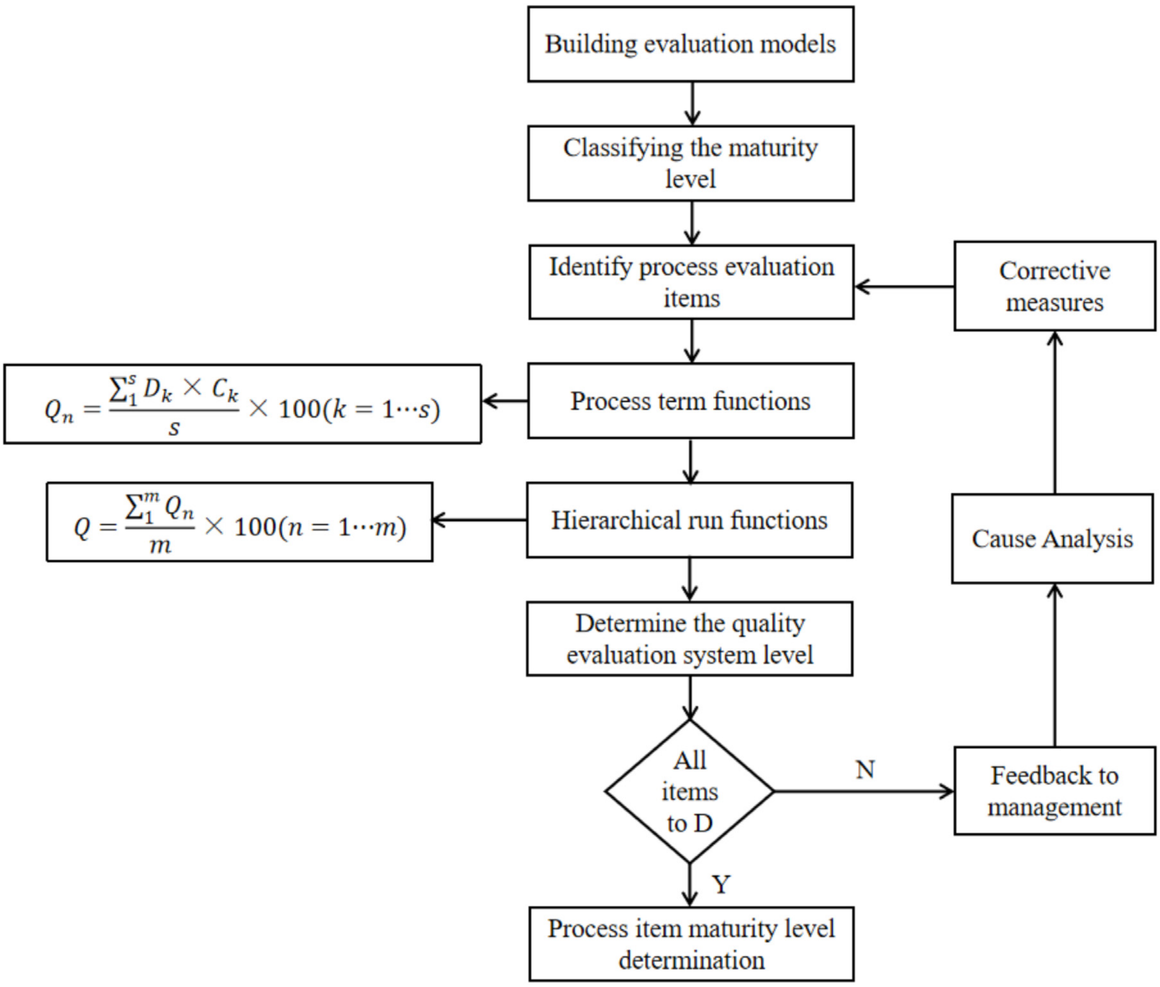

Fig. 1. Quality grading quantitative evaluation process.

5.1 Establish a process item determination group

The research team is composed of 6 people, including 2 senior engineers of petroleum special pipe research institutes, 1 university teacher and 3 master students. This study identified about 15 experts at three levels. Among them, there are five oil special pipe production personnel, oil special pipe experts and scholars, and oil special pipe related staff in the oil field. They require comprehensive subject knowledge, rich work or research experience in the oil field, and have keen academic judgment and professional ethics.

5.2 Process item judgment questionnaire

On the basis of literature review and expert interviews, the first round of expert consultation questionnaire was initially formed. The questionnaire is divided into three parts: the basic information of the experts, the main body of the questionnaire and the expert 's judgment results and main basis for the process item. After the first round of questionnaire recovery, combined with expert opinions and the results of the group discussion, the original process items were deleted, modified, merged and new process items were added. After finishing, the second round of

Table 6. Quantitative evaluation results of quality grading.

Process name	Process score (Q_n)	Maturity level	Process name	Process score (Q_n)	Maturity level
Manufacturing Management	80	Level C	Appraisal Evaluation	80	Level C
Standard Management	76	Level B	Acceptance basis	77	Level B
Technology Management	82	Level C	Oil field feedback	90	Level C
Design Development	80	Level C	Measurement benchmarks	80	Level C
Applicability evaluation	82	Level C	Inspection, testing specifications	85	Level C
Industry Review	85	Level C	Quality Supervision	83	Level C
Usage standards	77	Level C	Continuous Improvement	86	Level C
Site Management	76	Level C	Corrective measures	85	Level C
Value				81.5	Level C

expert consultation form was sent to experts. After the second round of questionnaires were all recovered, the consultation results were sorted out and analyzed again. The expert opinions were basically the same, and the questionnaire was ended.

5.3 "Usage Standards" quantitative analysis

Select 90% of the process terms of the "Usage Standards" as the base. And ten main items were selected to judge whether they are "Attainment." After considering that their data are valid, their "Attainment" is "1", $D_K = 1$. Then the "extent" of the determination, through the process items in Table 4 of the classification level, resulted in four out of ten items having a discrepancy: $C_k = 0.9$ ($k = 1$,...,4). Four items have two discrepancies, that is, $C_k = 0.8$ ($k = 5$, ..., 8). One item has three discrepancies, that is, $C_k = 0.6$ ($k = 9$). One item has more than four discrepancies, i.e., $C_k = 0.3$ ($k = 10$). The processing score of the process item "Usage Standards" is calculated by the formula (1).

$$Q_n = \frac{\sum_1^s D_k \times C_k}{s} \times 100(k = 1, \ldots, 10)$$
$$= \frac{4 \times 0.9 + 4 \times 0.8 + 1 \times 0.6 + 1 \times 0.3}{10} \times 100$$
$$= 77.$$

The scores of each process item were obtained sequentially by the above calculation. The quantitative evaluation scores of each process item are shown in Table 6.

Through the above process, the score of the non-API quality management system as calculated was 81.5, and the maturity level was C, which is in line with the current status of the non-API product management system.

It can be seen that the evaluation index of this hierarchical evaluation system is more quantitative and operational, and its pertinence is stronger. It can accurately identify the non-conforming items, at the same time, it can better explore the deep-seated reasons behind the problem, and improve it through effective measures. In addition, to ensure the quality grading system, quantitative evaluation results play an influential role in promoting the quality management of non-API OCTG. The grading and quantification work draws up a grade-by-grade re-evaluation. A grade carries out more than three times before a higher grade evaluation occurs. Moreover, to strictly control the quality grading evaluation, it is also necessary to introduce "veto items" in the quantitative evaluation work grading. If a process grade evaluation item "Attainment" to " 0", the grade will not be evaluated.

The evaluation method chooses 90% process terms of each evaluation item as the calculation base, which does not ultimately demonstrate the actual problems of non-API oil well pipe products in service at the oilfield site. And each item compared is based on the quality issues that arise at this stage. As the industry evolves, the process items that need to be assessed should be updated to create new assessment programs that accommodate new developments.

6 Conclusions

(1) The Capability Maturity Model Integration (CMMI) was used, and an evaluation method including process maturity level, items, indexes, and procedures was proposed to research non-API OCTG quality grading and quantitative evaluation method based on the Capability Maturity Model Integration (CMMI).

(2) The quantitative grading evaluation of the conventional non-API quality management system was carried out, the result value was 81.5 points, and the maturity level was C. This situation is in line with the current status of non-API product management. However, the method still has some limitations, and it cannot ultimately show the actual problems of non-API OCTG in oilfield service.

(3) To better control the quality of non-API OCTG and serve the development of oil field and non-API OCTG, the internationalization direction of integration and enhancement should be continuously adhered to in product design, production, and service management of non-API OCTG.

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