ICIC Express Letters
Part B: Applications
Volume **8**, Number **6**, June **2017**

ICIC International ©2017 ISSN 2185-2766
pp. 981–987

PROCESS OPTIMIZATION OF OIL-NATURAL GAS GATHERING AND TRANSFERRING FROM THE PERSPECTIVE OF INDUSTRIAL ENGINEERING

Wensheng Yang and Lin Sun

College of Economics and Management
Dalian University
No. 10, Xuefu Street, Jinzhou New District, Dalian 116622, P. R. China
yangwsh@126.com; sunlin_dl@163.com

Received November 2016; accepted February 2017

Abstract. *Process of oil-natural gas gathering and transferring starts with a stage from underground oil mining to wellhead process and ends with oil refining. The features of this phase include a large amount of the mixture of oil-gas and medium, long technics process, high investment, and high cost of processing. This paper systematically analyzes several critical problems of the crude oil gathering and transferring technology based on the analysis, evaluation, improvement and innovation of industrial engineering. It mainly involves: (1) a multi-subsystem linkage study based on system analysis to optimize the surface technology for the oilfield; (2) an economic decision model of multi-scheme optimization and technology upgrading of the oilfield; (3) a fundamental solution of the lengthy and complicated process of the oilfield, which emphasizes on the creative research & development as well as the application of the core production equipment. The simplified processing technology for the oil-natural gas gathering and transferring in the future is illustrated based on the field test of a new type oil-gas-water separator.*
Keywords: Industrial engineering, Oil-natural gas field development, Oil-natural gas gathering and transferring, Process optimization

1. **Introduction.** Oil and natural gas (ONG) are stored in the underground ONG stratum. At present, a displacement mining exploitation of water flooding and polymer flooding is adopted widely. After transporting the ONG to the ground network and processing devices by means of artificial lift, oil, natural gas and sewage are separated effectively. Then the crude oil with less than 5‰ water and the standard natural gas are transferred to the downstream industrial processing.

Generally, the production process of onshore oilfield is divided into four parts, which are water injection, oil production, gathering and transferring process (GTP), and the sewage treatment process (STP). The oil, gas and water separation is traditionally regarded as the primary processing of the gathering and transferring technology.

The development and production of the oil field is regarded as a progressive process. The oil and water well and the extraction liquid in the new production capacity are usually transferred into the system, and the original system is able to carry out the oil-gas-water process by means of the expansion method. It can be seen that the basic process structure has not changed, which brings the difficulties of optimization.

It is found that most of the recent researches settle down to the oil gathering network optimization, the water injection optimization of oilfield, and the gathering system optimization of the old oilfield. From different perspectives of optimizing the layout of oil and gas fields, Liu [1] and Li [2] discuss the star center point of well network, which is regarded as the basis of optimization, in order to determine the coordinates of each processing station facility. As for the studies on multi-stage star layout problem, Liu and Cheng [3], Wei and Liu [4] and other scholars propose different solving and optimization methods. Li and

Lou [5], Xu [6] put forward diverse optimization problems of gathering and transferring system based on the planning design and production practice. These studies regard the various processing stations in the process as a node based on the theory of large system, and it is lack of optimizing the internal structure of each node at the micro level.

This study analyzes the production process of ONG gathering and transferring based on the industrial engineering theory, which focuses on the technical interaction and productive influence between two processes of crude oil dehydration and sewage treatment. Furthermore, this paper proposes a new technology to change the stage output object, so as to achieve the simplification of the production process at all levels.

2. **Industrial Engineering-related Methods.**

Industrial engineering (IE) originated in the United States in early twentieth century. With the acceleration of China's industrialization, the application research of IE related technology has been developed extensively.

The basic functions of IE are consistent with those of management. As for an enterprise, the specific functions of IE are shown as six aspects: planning, design, program, control, analysis, innovation. Especially, improvement and innovation is the most common way in all kinds of industrial and management activities.

Method research is one of the most popular domains among 32 kinds of IE methods and technologies. However, there is no practical case study on the improvement of IE technology in the petroleum exploitation industry in China based on the analysis of the existing literature.

The method research refers to the scientific analysis on the existing or proposed working methods in order to develop a more convenient and effective method of work and achieve the goal of increasing productivity and reducing costs. The techniques of method research mainly include three categories, namely program analysis, operation analysis and motion analysis. By investigating and analyzing various working procedures, the optimization of the process is ultimately carried out.

System analysis is a necessary means for the development of IE. In terms of the petroleum industry, reliability analysis and evaluation of the engineering design scheme based on method research is necessary for both of the new project and the expansion project, including the optimization of the scheme [7].

3. **Basic Production Process of the Oilfield.**

The basic process of oilfield production is shown in Figure 1.

In the surface gathering and transferring process, the crude oil mixture is separated and processed by oil-gas-water three-phase separator. The index called the low water content of oil is $< 30\%$, and the oil content of sewage is < 1000mg/L which will be < 60mg/L after two times of settlement. Harmful oily sludge produced in the process of production needs harmless treatment. The basic production process is also regarded as the primary processing of ONG [8].

According to the production situation of the oilfield, we study on the primary production process of ONG based on the method research of IE. It is found that the primary processing is divided into two separate procedures during the production of the oilfield, namely GTP and STP. Almost all of the professional divisions of labor, regardless of the planning stage or the design stage, are classified based on GTP and STP. What is more, when considering with the difficulties of optimization and technology of the process, each major rarely considered it from the perspective of a whole system. This is a serious constraint to the scientific planning and optimization of the whole system.

According to the theory of industrial engineering, it is found that the production process of the oilfield is not only a continuous production process, but also a process of technological interdependence. For example, although it can facilitate the flow of oil in the well and the pipe network, adding the flow modifier makes more difficulties in the

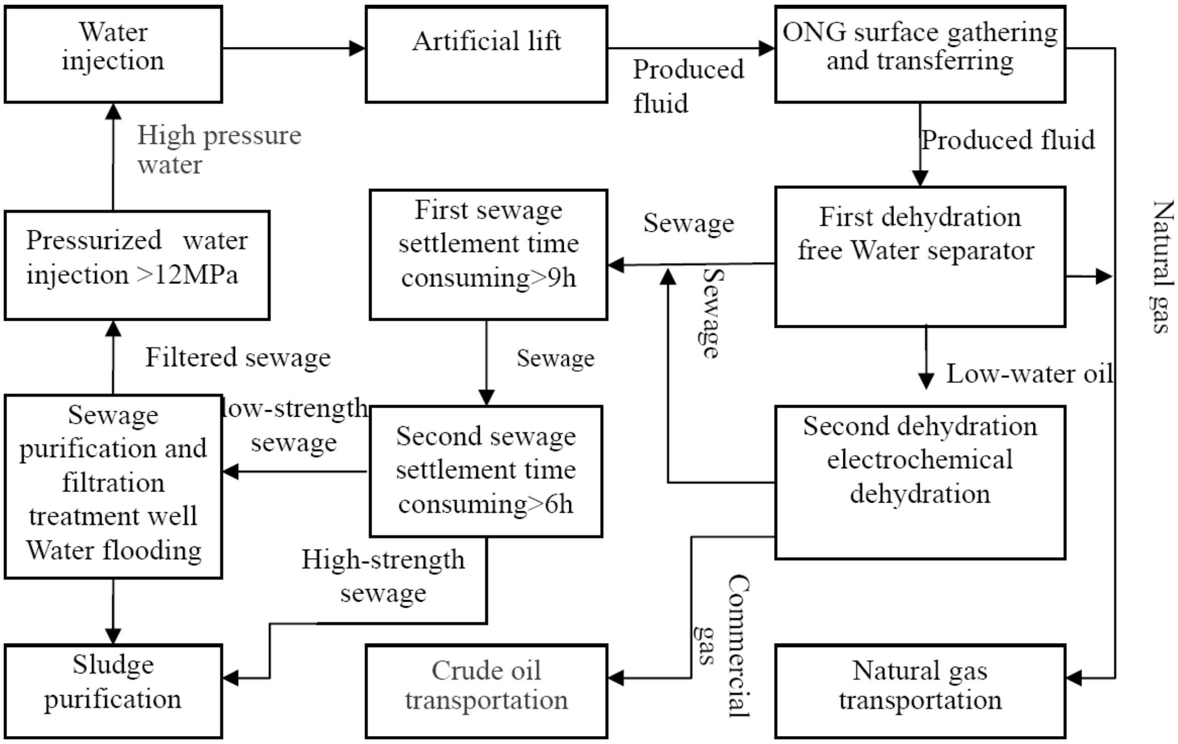

Figure 1. Flow chart of the basic process of the oilfield production

crude oil dehydration; the discharge of the free water three-phase converter has a direct impact on the effect of STP, whereas the index of the sewage filtration affects the oil recovery.

Table 1 shows the working procedures of an oilfield of 30000t of a daily fluid production. As for larger oilfields, the average daily output can reach to 20×10^4t which is equivalent to 6 times the production of this case. Obviously, the use of production facilities, network interconnection, integrated deployment of oil-water-gas resources makes the system much more complicated.

It can be seen that each step of the process is to control the production of its successor activities based on the relationship of the working procedure. As a result, it is required to consider the relative indexes of the precedence activities and the successor activities so as to select the appropriate production process and equipment.

It is found that the oil gas water three-phase separator (OGWS), which determines the selection of crude oil dehydration equipment and oily waste water treatment equipment, is the core equipment of the system in spite of the interdependence of processes. In other words, high efficiency of OGWS can greatly reduce the capacity of subsequent processing, thereby reducing the cost of construction.

4. **Optimization Model Analysis of the GTP in the Oilfield.** This paper focuses on exploring the decision-making optimization problem of programs based on economic indicators, which assumes that the reliability of all kinds of options can meet the production requirements. As for the technical upgrading or transformation of the constructed oilfield, the lowest total cost method based on dynamic programming model is usually used to judge the merits of the program. The amount of treatment of the production process is small, and the process index includes two aspects, namely quality and average cost. The total cost of the process or equipment can be used as a variable to establish the model during the analysis [9].

TABLE 1. The relationship of each working procedure and the index of the production process in a certain oilfield

No.	Name	Precedence activities	Successor activities	Import index	Export index
1	Water flooding	10	2	Injection index of single well	Flow pressure of the oil well, static pressure index
2	Artificial lift	1	3	Effective fluid level	Effective delivery pressure
3	Surface gathering and transferring	2	4, 11	Temperature $> 40°$C	Primary separation of ONG
4	Oil-gas-water separation	3	5, 7	Temperature $> 40°$C	Water of the crude oil $< 30\%$ Oil of the sewage < 1000mg/L
5	Electrochemical dehydration	4	11, 6	Water of the crude oil $< 30\%$	Water of the crude oil $< 0.5\%$ Oil of the sewage < 300mg/L
6	First sewage settlement	3, 4	7	Oil of the sewage < 1000mg/L	Oil of the sewage < 200mg/L
7	Second sewage settlement	6, 5	8	Oil of the sewage < 200mg/L	Oil of the sewage < 60mg/L
8	Sewage filtration and tank storage	7	10, 9	Oil of the sewage < 60mg/L	Oil of the sewage < 8mg/L Suspended matter < 3mg/L
9	Sewage treatment	8	6, 12	High concentrated sewage	High concentration sewage
10	Medium pressure	8	1		Outlet pressure > 15MPa
11	ONG transportation	3, 5		Water of the crude oil $< 0.5\%$	
12	Sludge treatment	6, 8			Water of the sludge $< 0.25\%$ Oil of the sludge < 100mg/L

4.1. **Economic evaluation model of multi-process optimization in new capacity engineering.** Figure 1 and Table 1 list the basic process relationship and the control parameters of oil production. A network diagram of the oilfield GTP can be drawn according to the process relationship diagram and index constraints.

Assuming that n denotes the number of processes that are needed from an initial state S to the final state S_k $(k = 1, 2, \ldots, n)$, $d(S, S_k)$ denotes the corresponding process cost. The minimum process cost $f_n(S)$ from S to S_k can be described as

$$f_n(S) = \min \begin{cases} d(S, S_1) + f_{n-1}(S_1) \\ d(S, S_2) + f_{n-1}(S_2) \\ \cdots \\ d(S, S_k) + f_{n-1}(S_k) \end{cases} \tag{1}$$

The dynamic programming network diagram can be used to solve the equation, in which the cost of each process can be calculated according to the industry standard and the process parameters of the corresponding equipment and supporting [10].

4.2. **Economic evaluation optimization model of the process and equipment upgrading.** In addition to technology upgrades (denoted by m), the feasible options also include: continuing to use the old equipment (process) (denoted by 0), overhauling the old equipment (process) (denoted by r), replacing the old equipment (process) with the same structure but new one (denoted by n) and replacing the old equipment (process) with more efficient and better structure one (denoted by h). The purpose of the decision is to choose the minimum total cost (including the construction cost, the operation and maintenance cost, and the discounted algebraic sum of salvage) of the options [11].

$$TC_0 = \left(\sum_{j=1}^{n} C_{0j}r_j - V_{0L}r_n\right) \Big/ \beta_0 \tag{2}$$

$$TC_n = \left(K_n + \sum_{j=1}^{n} C_{nj}r_j - V_{00} - V_{nL}r_n\right) \Big/ \beta_n \tag{3}$$

$$TC_h = \left(K_h + \sum_{j=1}^{n} C_{hj}r_j - V_{00} - V_{hL}r_n\right) \Big/ \beta_h \tag{4}$$

$$TC_m = \left(K_m + \sum_{j=1}^{n} C_{mj}r_j - V_{00} - V_{mL}r_n\right) \Big/ \beta_m \tag{5}$$

$$TC_r = \left(K_r + \sum_{j=1}^{n} C_{rj}r_j - V_{rL}r_n\right) \Big/ \beta_r \tag{6}$$

where $(TC_0, TC_n, TC_h, TC_m, TC_r)$ denotes the total cost of n years, $(C_{0j}, C_{nj}, C_{hj}, C_{mj}, C_{rj})$ denotes the operation cost of the jth year, $(V_{0L}, V_{nL}, V_{hL}, V_{mL}, V_{rL})$ denotes the salvage of the nth year. $(\beta_0, \beta_n, \beta_h, \beta_m, \beta_r)$ denotes the production efficiency coefficient of each option, (K_n, K_h, K_m, K_r) denotes the corresponding investment and V_{00} denotes the sale value of the old equipment (process) in the year of decision-making. r_j and r_n respectively denote the discounted coefficient of the jth year and the nth year.

As for the production facilities of oilfield, the production of general process has been established. As a result, the production efficiency value β can be set to 1 under the premise of meeting the capacity. While as for a variety of technical update process or new types of efficient equipment, they can be compared based on the above model and further compute the minimum of TC, and the final result is the optimal solution.

5. **Field Experiment and Future Optimization of Main Equipment.** According to the importance of each process, this study concludes that the OGWS is the key equipment for the whole process design. The improvement of the processing effect can directly reduce the selection difficulties in the equipment and process of the crude oil dehydration and the sewage treatment. It can be concluded that the experimental research of high efficient OGWS is an important research of the system optimization. That is, explore the optimization of the technical route from the perspective of the production process technology.

5.1. **Basic principle and index of common OGWS.** The OGWS used in oil field adopts the principle of gravity sedimentation, which realizes the separation of ONG by the separation of gas and liquid and the separation of crude oil and water. The design indexes of the conventional OGWS are as follows: the water content of oil and water mixture is lower than 30%, and the oil content of the sewage is lower than 1000mg/L.

Table 2 shows the daily basic production data of an oilfield with an annual output of 500×10^4t. It can be seen that the production parameters vary greatly with the way of working and the properties of the mixture.

TABLE 2. The production data of ONG GTP stations of a certain oilfield

Station No.	*Fluid volume (t)*	*Polymer quantity (mg/L)*	*Water discharge (t)*	*Oil output (t)*	*Water cut (%)*	*Water of the first oil production (%)*	*Oil of the first water discharge (mg/L)*	*Fluid temperature (°C)*	*Dosage (kg)*
A	21166	314	19053	1808	90.01	23	700	41	700
B	30926	303	29138	1977	92.57	23	1530	42	1006

5.2. **Basic structure and index of high efficient OGWS.** Based on the traditional production method of the OGWS, the new high efficient OGWS optimizes the internal structure of the equipment, flow field and coalescence material, which depends on the incompatibility of oil, gas and water and the density difference between different phases. The technical index of the efficient separation of oil gas and water includes the water content of the dehydrated crude oil $\leq 0.3\%$ (internal controlling standard) and $\not> 0.5\%$ (industry standard), the oil content of the dehydrated sewage $\leq$ 400mg/L [12].

5.3. **Field test of high efficient OGWS.** In this experiment, two $\Phi 3.6\times 16$m OGWS are designed in an ONG GTP station of a high water content oilfield in Daqing (the station B in Table 2), together with the original system operated in parallel. Sewage discharged into the sewage treatment system, and the oil with low water content connected with the conventional separator oil outlet and entered into the next process together. Table 3 shows the average data for the equipment operation in 3 months.

TABLE 3. Experimental data of the high efficient OGWS

Sample	*Fluid volume*	*Water cut of fluid (%)*	*Polymer concentration (mg/L)*	*Water of crude oil (%)*	*Oil of water (mg/L)*
1	6950∼7660	90.2∼91.1	245∼295	0.60∼2.1	269∼425

It can be seen based on the experimental analysis that the experimental data is significantly better than the corresponding indicators of the original system, of which the water content of crude oil fell 10% and the oil content of sewage fell 1105 mg/L. Li and Luo maintain that the high efficient dehydration process of OWGS is suitable for the small station of gas-oil dehydration, whereas it is not suitable for the GTP of large oil field which has preliminarily separated the natural gas [5].

The experimental data in this study demonstrate that despite the failure to meet the design requirements, the OWGS can effectively improve the processing efficiency of the whole system. It can reduce the construction scale of the latter working procedure (sewage sedimentation and filtration) if it is put into practice. From the perspective of the whole system, it is necessary to explore a high efficient OWGS suitable for large-scale ONG processing to solve the technical bottleneck.

5.4. **Case analysis of the crude oil GTP optimization in the oilfield.** According to the experimental results in this study, a construction plan is carried out for the GTP station of a certain medium water content (50-80%) oilfield with 419 oil and water wells, as well as daily production of 1000t fluid and 470t crude oil. Two options are selected for the construction planning; one is the conventional design, and the other one is to employ the efficient OGWS as a primary dehydration process. The basic process of these two options is similar, but the construction scale of each process is quite different. For example, the volume of the electrochemical dehydration device reduces 1/4 and the corresponding investment decreases ¥320,000; the volume of the sewage sedimentation tank reduces from

$1000m^3$ to $500m^3$ and the corresponding investment decreases ¥1,050,000; meanwhile the specified discharge of all kinds of matching oil and water pump is turned down a notch respectively.

According to the estimates, the investment of the conventional design program is ¥21,259,900, whereas the investment of the efficient OGWS is ¥19,710,200. Therefore, the efficient OWGS option is selected based on the optimization evaluation model and financial evaluation method. When the efficient OWGS is adopted, it is possible to save ¥300,000 of the maintenance cost, ¥250,000 of the operation cost, ¥200,000 of the material cost, more than ¥2,200,000 of cooperation fee and $30,000m^3$ of water a year. Based on the project economic evaluation of ten-year production, the incremental financial net present value reaches ¥7,114,200 and the incremental investment recovery period is 5.4 years. As a result, the project is also feasible.

6. **Conclusions.** In this paper, some key problems in the process of crude oil gathering and transferring are analyzed based on the evaluation and innovation of IE theory, which involve: (1) an economic decision-making model is established for multi-scheme optimization and technical upgrading of the oilfield; (2) through the field test, it is concluded that the improvement of the efficiency of OGWS, which is regarded as the key equipment of the system, will greatly promote the optimization of the whole system; (3) the optimization of oil field gathering and transportation should be based on the optimization of network layout and internal optimization of each node, and the node optimization should be treated as the basic research work in order to ensure the reliability of the overall optimization; (4) focusing on the time of optimization and the critical use of the system can improve the efficiency of asset utilization; (5) carrying out a variety of analysis on technical reliability and system function importance of ONG GTP system is also helpful to control the cost of equipment manufacturing.

REFERENCES

[1] Y. Liu, Layout optimization design of gathering and transportation network system with network topology relationship, *Petroleum Engineering Construction*, vol.16, no.3, pp.7-9, 1990.
[2] S. W. Li, Optimization of gas gathering stations, *Natural Gas and Oil*, vol.12, no.4, pp.5-8, 1994.
[3] Y. Liu and G. D. Cheng, Optimal design of N-level star network, *Journal of Dalian University of Technology*, vol.29, no.2, pp.131-137, 1989.
[4] L. X. Wei and Y. Liu, Obstacle topological layout optimization design of oil-gas gathering and transferring system, *Acta Petrolei Sinica*, vol.27, no.6, pp.120-124, 2006.
[5] J. X. Li and Y. H. Lou, Object design of ONG gathering and transportation system in Daqing oil field, *Petroleum Planning & Engineering*, vol.25, no.6, pp.1-5, 2014.
[6] X. M. Xu, Optimization design of oil/gas gathering and transportation system based on the fuzzy clustering method, *Petroleum Engineering Construction*, vol.42, no.2, pp.5-9, 2016.
[7] E. S. Qi and Y. F. Huo, *Industrial Engineering and Management*, Science Press, Beijing, 2011.
[8] J. J. Dai, Z. Y. Dong and Y. Tian, *ONG Gathering and Transferring*, Petroleum Industry Press, Beijing, 2012.
[9] R. F. Shen, *Operational Research*, Machinery Industry Press, Beijing, 2009.
[10] W. Chen, *Technological Economics*, Tsinghua University Press, Beijing, 2012.
[11] J. J. Fu, *Industrial Technological Economics*, Tsinghua University Press, Beijing, 2002.
[12] Z. Q. Wang and N. P. Ma, Application effect analysis of HXS type oil-gas-water three phase separators, *Oil Field Equipment*, vol.36, no.5, pp.80-83, 2007.