Development of Produced Water Treatment System Using Magnetic Separation with Magnetic Particles as Seeding Agents

Y. NAKANO, M. WATANABE, S. TERUI, and M. MORITA

Matsudo Research Center, Infrastructure Systems Company, Hitachi, Ltd.,

Kami-Hongo 537, Matsudo-shi, Chiba-Ken, 271-0064 Japan

Abstract

This study shows the development of a produced water treatment system using flocculation and magnetic separation, and the improvement of the prediction formula on floc residual rate to evaluate magnetic separation performance. Previously, magnetic separation conditions were determined based on a number of experiments on various types of influent that depends on wells. Therefore it took time substantially to design specifications for each system. A simple design process diagram has been established by considering influential factors to magnetic separation conditions and conducting simple experiments using synthetic water. The developed prediction formula can realize speedy and effective proposals on the system customized for each site.

Key Words: Magnetic particles, Magnetic seeding, Magnetic separation, Produced water

I. INTRODUCTION

In the Oil & Gas industry shifting its oil production fields from onshore to offshore, the amount of produced water generated containing oil is increasing every year [1]. Since the produced water contains oil of high concentration, the treatment methods of produced water to meet local environmental standards on discharge are needed. However, most offshore oil platforms do not have enough space for the treatments, and the produced water is thus treated after being transported ashore through pipelines. Since crude oil and produced water are conveyed through the pipelines with limited transport capacity, the increase of produced water contained in the crude oil imposes economically inefficient problems [2] [3]. To solve these problems, our company has developed Flocculation Magnetic Separation system as a small-footprint oil separating system which is installable on an offshore platform [4]. And the system generates treated produced water to meet local environmental standards on oil concentrations, not only enabling direct sea discharge of produced water but also increasing crude oil production. This system, utilizing magnetic particles as seeding agents, consists of a flocculation process to form magnetic floc containing coagulated oil, and magnetic particles and a magnetic separation process to remove the floc. Previously, magnetic separation conditions were determined through a number of experiments using various types of produced water of which the water quality depends on wells. Thereby it was a time consuming procedure to design specifications on each system. This study shows a simple design method by considering influential factors to magnetic separation conditions and conducting simple experiments using synthetic water. This newly developed method realizes speedy and effective proposals on the system customized for each client.

II. EXPERIMENTAL METHODS

A. Flow of produced water treatment system

Flocculation and magnetic separation system mainly consists of flocculation process and magnetic separation process. Magnetic particles and inorganic coagulants chemicals are injected into the produced water which contains oil and suspended solid (SS). The flocculation process consists of two types of mechanical reactors: a flash mixer and a flocculation reactor. The magnetic particles and inorganic coagulants injected from the chemical injectors are uniformly mixed in the flash mixer at high agitation speed. In the process of sending the water from the flash mixer to the flocculation reactor, high polymer flocculants is injected. The agitation speed is slower in the flocculation reactor than in the flash mixer. In this agitation process, floc containing magnetic particles and aggregated particles are formed in the flocculation reactor. Since the floc contains magnetic particles, it is magnetically attractive at the next process, magnetic separator. In the magnetic separation process, the floc is removed quickly by attractive force of magnets. Therefore, this system removes oil contained in the floc. Accordingly, oil residual rate and floc residual rate is equal. Therefore, oil separation performance is evaluated with floc residual rate.

B. Subject

Motion of floc is mainly influenced by magnetic force and fluid drag force. And the fluid drag force depends on kinetic viscosity through Reynolds number. Thereby, motion of floc is influenced by kinetic viscosity. Therefore, it is one of the important subjects to improve the prediction formula covering wide range of kinetic viscosity, which influences the floc removal performance through fluid drag force operating on floc motions. Produced water quality varies on different sites and kinetic viscosity varies as well. In the present design level of diagram on magnetic separators, prediction formula on floc residual rate is applicable in case of kinetic viscosity with about $1.0 \mu\text{m}^2/\text{s}$. Accordingly, the proposal suitable for customer needs is not offered. This study is aimed at improvement on the prediction formula to evaluate floc residual rate reflecting influential factors for magnetic separation performance.

C. Equipment and contents

Figure.1 shows a diagram of treatment system which was applied for this experimental study. Floc residual rate can be expressed in plug flow model or completely mixing model. In the analysis of the experimental data gained in the experiments, these two types of modeling were applied for the data. And proper prediction model on floc residual rate was formulated through the data analysis. The data based modeling study gained the improved prediction formula on floc residual rate reflecting influential factors to evaluate magnetic separation performance. Figure.2 shows the experimental setup of straight flow column with magnets aligned on one side of flow channel. This structure simulates an actual magnetic separators offered by our company. This prediction formula provides various design of magnetic separation processing time.

Fig. 1 Process diagram of treatment system.

Fig. 2 Schematic diagram of magnetic separator equipment.

III. RESULTS AND DISCUSSION

A. Reflection of influence factor on magnetic separation performance

Figure.3 shows a relationship between contact time and floc residual rate. Figure.4 shows a relationship between specific kinetic viscosity ratio ν/ν_0 and specific adsorption coefficient ratio k/k_0 .

Fig.3 Relationship between contact time and floc residual rate.

Fig.4 Relationship between ν/ν_0 and k/k_0 .

Here, specific kinetic viscosity ration is defined with normalization by the kinetic viscosity of fresh water with $10^{-6}\text{m}^2/\text{s}$. Floc residual rate increases as kinetic viscosity increases. This shows that the magnetic separation performance decreases as kinetic viscosity increases, since fluid drag force increases under the conditions of higher kinetic viscosity compared to magnetic force. The formula of the experimental floc residual rate is approximately expressed well as formula (1). Therefore, completely mixing model is considered to be appropriate to estimate the floc residual rate.

$$\eta = \frac{C}{C_0} = \frac{1}{1 + kt} \quad (1)$$

η :Floc residual rate (-), C :Effluent floc concentration (mg/L), C_0 :Influent floc concentration (mg/L), k :Adsorption coefficient (S^{-1}), t :Contact time (s)

In the figure 4, relationship between k/k_0 (Specific adsorption coefficient ratio) and ν/ν_0 (Specific kinetic viscosity ratio) is proportional connection. Specific adsorption coefficient ratio has an inverse relationship with specific kinetic viscosity ratio, expressing as formula 2. The value of the exponent in this formula is between -1 and -2.

$$k / k_0 \propto (\nu / \nu_0)^\alpha, \quad -2 < \alpha < -1 \quad (2)$$

IV. CONCLUSIONS

In the study on the development of produced water treatment system using magnetic separation with magnetic particles as seeding agents, floc residual rate is approximately expressed in completely mixing model. Adsorption coefficient is formulated as a function of kinetic viscosity. This formula covers wide range of kinetic viscosity.

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