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DEVELOPMENT OF FREE WATER KNOCK-OUT TANK BY USING INTERNAL HEAT EXCHANGER FOR HEAVY CRUDE OIL

Ismail ✉
Department of Mechanical Engineering[1]
ismail@univpancasila.ac.id

Ambar Tri Mulyanto
Department of Master in Mechanical Engineering
Universitas Pancasila
Jalan Borobudur, Menteng, Jakarta Pusat, DKI Jakarta, Indonesia, 10320

Reza Abdu Rahman
Department of Mechanical Engineering[1]

[1]Universitas Pancasila
Jalan Srengseng Sawah, Jagakarsa, Jakarta Selatan, DKI Jakarta, Indonesia, 12640

✉**Corresponding author**

Abstract

Reactivation of an old oil well can be explicitly calculated to maximize crude oil production. The biggest challenge with the activation process is the crude oil content in old wells, which is not feasible to meet the specified minimum standards. In the case of the Bunian oil field, Indonesia, the crude oil produced has high water content. It causes a decrease in the quality of production and also hinders production capacity. The production scheme applied to the Bunian field has a storage tank that functions to reduce water content using the gravity method, but this is less effective. Let's modify the storage tank into a heat exchanger tank through the engineering design process and labeled it as a free water knockout tank (FWKO). The FWKO is made of a multi-pass tube heat exchanger. The experiments are conducted through three phases' tests before deciding the final design. From the test, the change in water content is varied with temperature differences of the working fluid and crude oil. The lowest water content is obtained at 0.5 % at final tests. After analyzing the characteristic of each test result, the final design is taken by adjusting the suitable working fluid temperature and pressure. Finally, by using suitable parameters, the average water content of crude oil is decreased up to the minimum requirement (< 0.1 %). The design of FWKO is considered simple with an excellent performance and can adapted easily. The FWKO able to process crude oil with water content ≤20 %, where it suitable for waxy oil well. The working fluid can be processed both in liquid and gas state. Furthermore, the heating source for the working fluid is gained from the gas flare by using thermic heater. Thus, it does not require an extra heating source for the heat exchanger.

Keywords: dewatering, crude oil, heat exchanger, oil well, water knock-out.

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1. Introduction

An old oil-well is relatively abandoned caused by several factor such as low productivity and high operational cost. However, the old oil-well able to produce significant crude oil which can be refined for particular product like wax, fuel oil and lubricating oil [1]. Hence, the reactivation process of old oil-well gains significant interest nowadays [2, 3]. Reactivation for the old oil-well required minimum cost since the purpose is not for large production; then, the production equipment should be economically feasible [4–6]. Furthermore, it can be combined with hydrocarbon-geothermal well for increasing the feasibility of the production [7]. However, some deposit remains within the extracted oil [8]. It makes the quality of the produced crude oil is under the required standard (water content < 0.5 %, salt content < 7 pounds per thousand barrel (ptb)). It makes the retention time should be longer to achieve the required standard. Unfortunately, extended retention time makes the production capacity decreased too and makes the operational cost increase.

In order to see the problem from a better perspective, the schematic model of production is shown in **Fig. 1**. The crude oil from the well is pumped to the gathering manifold, then proceed to separate the gas and liquid where most of the gas burned (for flaring) and a small portion of the gas is sent to gas engine generator. The liquid oil, which consists of water and oil, proceeds to the wash tank for water-oil gravitational separation. After initial separation, the oil flows to the storage tank (V–04) then pumped to the final storage tank (T–101). The water from the separator tank proceeds to the skim tank and surge tank, then pumped to the water injection facility. The retention time on the wash tank (T–102) is a short while, and it makes the water content on the oil higher than 0.5 %.

One method that effectively reduces the water content in crude oil is heat treatment, known as dewatering [9]. The temperature of crude oil from the wash tank (T–102) to the storage tank (V–04) is 37 °C, which is lower than the minimum temperature to weaken the emulsion bond of the crude oil (40 °C). When the environment temperature decreases, the water content increases as the temperature from the wash tank decreases. It makes the crude oil needs to be heated in the storage tank (V–04). The storage tank (V–04) is not specifically designed for heat treatment purposes at large quantity production or high water-content crude oil.

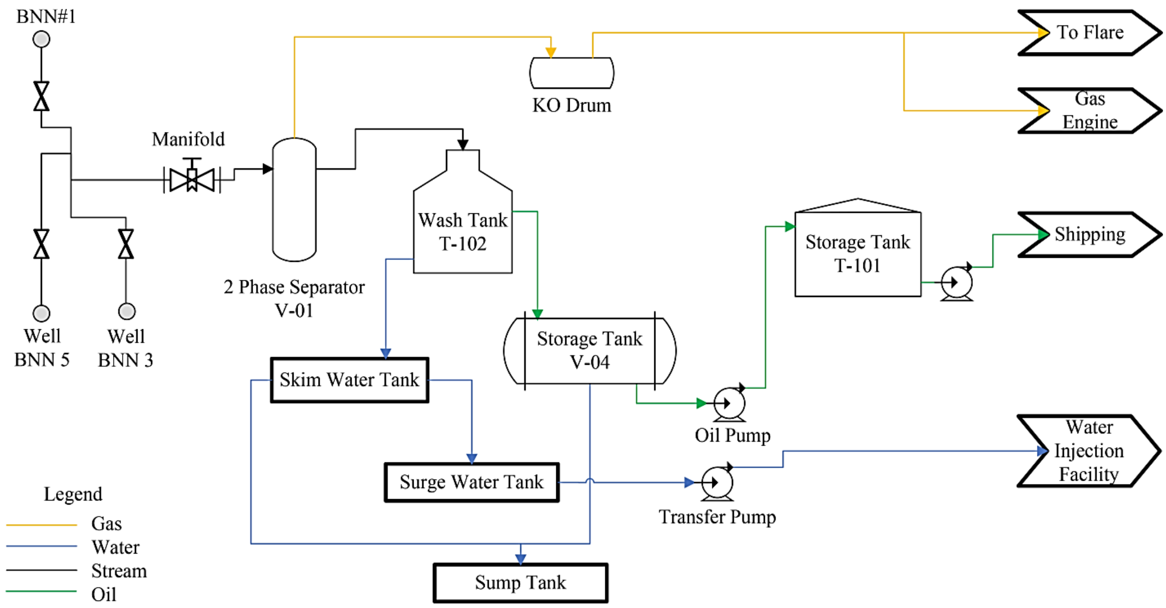


Fig. 1. Schematic production on the site (Bunian, Indonesia)

An electric heating system might be useful for heat treatment [10], but it requires extra equipment for the plant and grid connection, which increases the cost. Another solution should be taken by considering all parameters, mainly cost and thermal energy source. For instance, by using root cause analysis and first-principle design we come up with the idea to use a non-electric thermal heat exchanger inside the storage tank (V–04) [11]. This method also recommended for extracting geothermal energy from the oil wells [12]. Another study also reports that a heat exchanger in a storage tank can effectively reduce the water content and salt content [13]. Thanks for the knowledge sharing among researchers and engineers, which helps us gain useful information for the design [14]. Y.-L. Nian, et al. [15] studied the hot water – CO_2 – chemical flooding for oil recovery experimentally and found the heat transfer of the reservoir is depended on the hot water injection and provides sufficient information regarding the temperature of the working fluid. J. Tan, et al. [16] studied the phase inversion of the heavy crude oil at various temperatures and helped us determine the design's temperature characteristic. J. Zhao, et al. [17] analyzed the effect of waxy crude oil specific heat capacity numerically and found the temperature effect on the specific heat capacity of the waxy crude oil. This work aims to promote a better method for the dewatering process of heavy crude oil with high water and salt contamination. The method is expected to develop and adapted for oil production across the globe. Furthermore, the design is expected to use external heat sources from waste heat [18] or solar power (concentrated solar power) [19]. Thus, it will help develop a green production system in oil production to minimize the environmental effect (besides the produced oil itself).

2. Materials and Methods

Root cause analysis and first-principle design help the authors to find the root cause of the problem. From the root cause, a series of steps for design optimization through the engineering process is conducted. The step is started by using a typical design procedure in the engineering field by gathering the information from the initial design (components, material properties and experimental data) for analysis and evaluation purpose [20].

Components, material properties both for the design and production process, and experimental data are taken as a production process for the initial design to evaluate the existing model (storage tank V–04). The essential data from the production process is outlined in **Table 1**.

The average crude oil is dependent on the inlet temperature and the outlet temperature; even at the maximum temperature, it is still less than the targeted temperature (40 °C); the problem mainly caused by the inlet temperature of the crude oil, which is affected by the environment temperature and the basic design of the storage tank. The optimization approach is conducted according to typical steps in thermal optimization process: modelling, simulation, design evaluation, obtaining the acceptable design and optimal design [20].

Understanding the basic physical process and system on the production site (**Fig. 1**), and considering the overall production efficiency (waste heat recovery for this case) and ability to using an alternative heat source (solar heating system), the working fluid for the heater should be able to meet the requirement [21]. Let's design a new fluid line for the working fluid to the heater tank, as shown in **Fig. 2**.

Taking into account the parameters in **Tables 1, 2** for basic specification of the storage tank (V–04), and also variable conditions like the volume of the crude oil inside the tank, let's find the required overall heat transfer inside the tank is ranging between 150 W/m^2 °C–1,200 W/m^2 °C for the working fluid Hydraulic Oil ISO 46 with the thermophysical properties and operational characteristic as shown in **Table 3**.

Table 1
Data from the initial production process

Parameters	Value	Unit
Crude oil production rate	79.5–159	m^3/day
The crude oil inlet temperature	30–36	°C
Crude oil outlet temperature	37–39	°C
The average density of the crude oil	848	kg/m^3
Average kinematic viscosity (μ)	5.6	cSt
Average specific heat	2.21	kJ/kg·°C

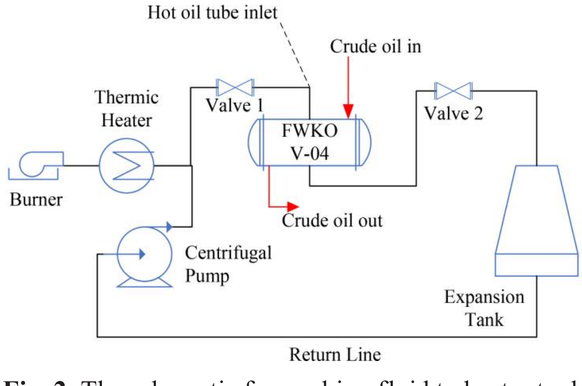


Fig. 2. The schematic for working fluid to heater tank

Table 2

Basic Specification of storage tank V-04

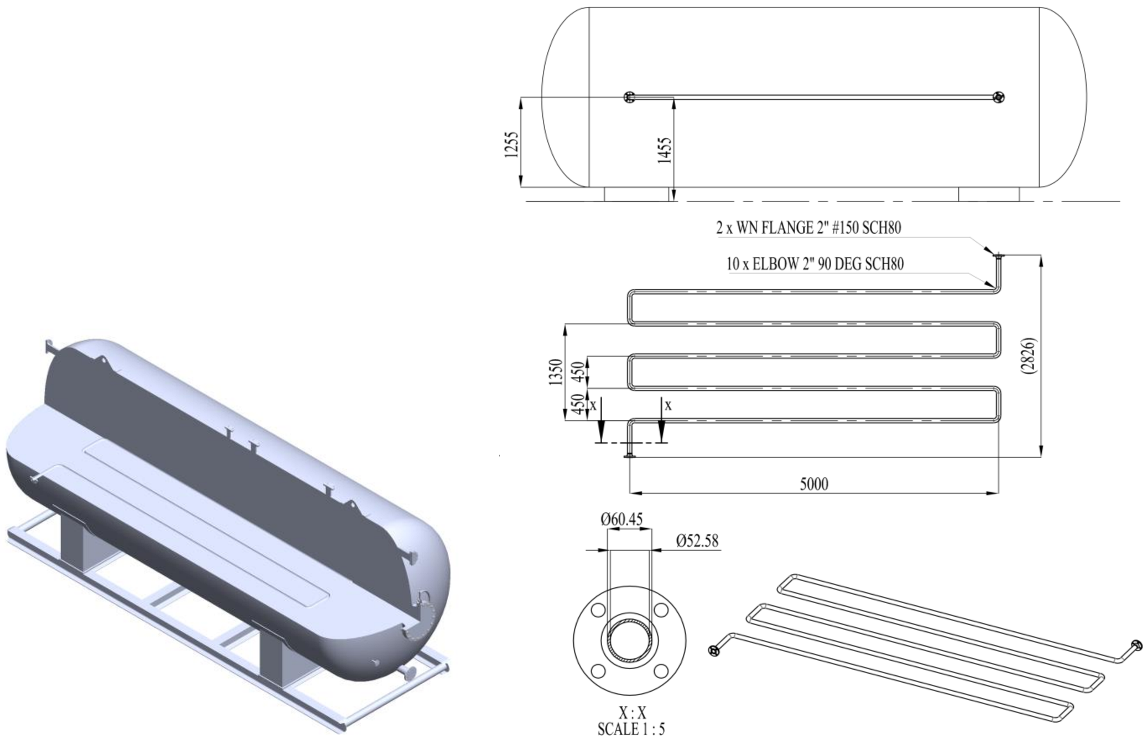
Item	Value	Unit
Length	6,000	mm
Width	2,500	mm
Capacity (liter)	34,040	Liter
Capacity (barrel)	214.1	Barrel
Head type	2:1	Ellipsoidal
Designed pressure	1.034	Bar
Designed pressure	15	Psig

Table 3

Hot fluid properties and operation limitation

Data working fluid	Value	Unit
Flow rate (max.)	14	m^3/hour
Density	833	kg/m^3
Mass flow	3.2	kg/s
Specific heat	2.72	kJ/kg·°C
Working temperature	80	°C
Specific gravity	0.875	kg/m^3
Viscosity	7.0	CST

Considering the basic model of the tank (V–04), as shown in **Fig. 3**, ***a*** the multi-pass tube heat exchanger is suitable for locating inside the tank [22]. The design process is started from the dimension and model of the tank V–04 (**Table 1**).



a *b*

Fig. 3. Design of free water knock-out: *a* – basic design the storage tank and heat exchanger position; *b* – the detail dimension of the heat exchanger

The heater tank is labeled as Free Water Knock Out (FWKO). All parameters in the production equipment [23, 24], critical parameters for the crude oil [25] and heat transfer characteristic for crude oil [26, 27] are taken for numerical approach as part of the simulation step. Once the numerical simulation is solved, the heat exchanger's final design is obtained and shown in **Fig. 3, *a, b***.

Testing is carried out in several stages, namely stages 1, 2 and 3, to examine the performance of the heat exchanger design that has been made. Each phase is made of a different duration. Minor improvements are adjusted based on the test results in each phase. Data were collected every 10 minutes with the consideration of maintaining the quality of the data obtained. The measurement points are inlet (T_{H1}) and outlet temperature (T_{H2}) of hot oil in thermic heater; inlet temperature (T_{H3}) and outlet temperature for heating fluid and inlet temperature (T_{C1}) and outlet temperature (T_{C2}) for crude oil in FWKO. Sample from crude oil is taken after passing the FWKO and analyzed for the density (ASTM D1298) and basic sediment and water (ASTM D4007).

3. Results and discussion

Before conducting the experiment test, the FWKO proceeds to NDT (Non-Destructive Tests) to ensure the safety measurement. According to the NDT result, the apparatus is considered safe to be used. The experimental test process is carried out in several stages to determine the effectiveness of the design made. The most important indicator of testing, in the end, is the water content data of each sample of crude oil. The test is focused on gathering the temperature difference in heating fluid and crude oil. **Fig. 4** presents the data for testing phase 1, which was carried out for 100 minutes.

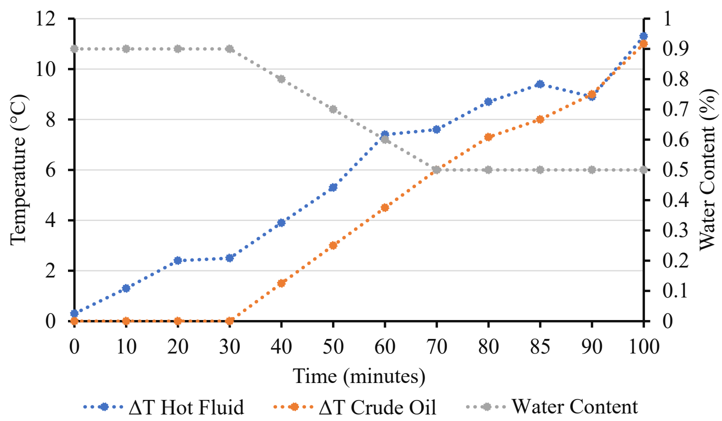


Fig. 4. 1st phase experiment

The heating rate in the first 30 minutes does not cause an increase the temperature of the crude oil because the preheating process is in progress. As the heating rate increases, the crude oil temperature begins to rise, which make the water content in crude oil begins to fall. The mean temperature differences in hot fluid and crude oil are 5.75 °C and 4.19 °C, respectively. The average heat loss for the heating fluid is 4.98 °C. The losses are measured by the difference between the outlet temperature of the thermic heater to the inlet of FWKO.

Design improvements were made specifically to minimize heat losses from the burner to the FWKO tank. The test is carried out for a longer time to obtain more relevant test results. There was an increase in the mean temperature difference for hot fluid (9.58 °C) and for crude oil, a decrease to 3.32 °C. As seen in **Fig. 5**, the preheating rate occurs longer than phase 1 because of the quality of the produced oil, which is waxy crude oil where the thermal characteristic of the oil is extremely low [19]. Apart from this, improvements in the pipeline from the burner to the FWKO reduced heat losses from the hot fluid, with the average temperature loss falling to 4.3 °C.

During the third experiment, the water content of the crude oil starts to fall at a faster time than the previous test. From **Fig. 6**, it can also be seen that the initial heating of crude oil does not take a long time. It makes the decrease in water content in crude oil occurs immediately. The mean temperature difference in the hot fluid was slightly lower than the second test, which is 8.15 °C. However, the mean temperature difference for crude oil increased significantly to 5.94 °C, and the total heat loss was decreased up to 3.53 °C.

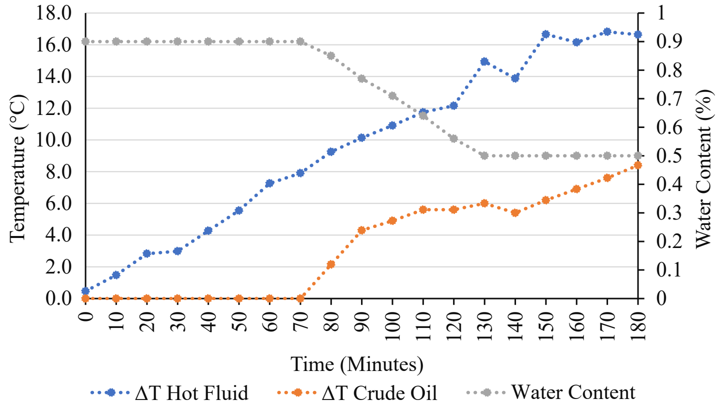


Fig. 5. 2nd phase experiment

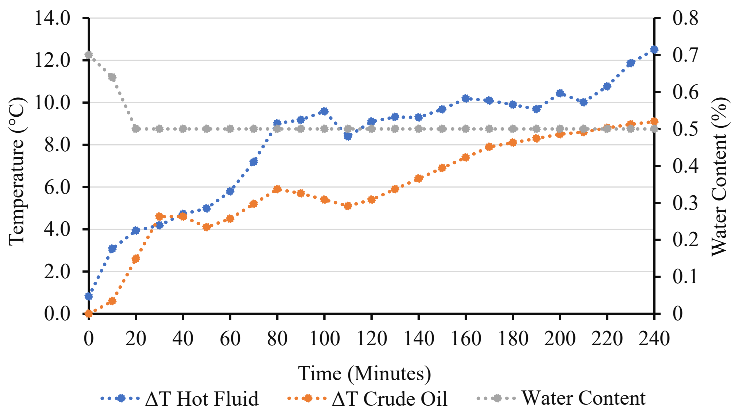


Fig. 6. 3rd phase experiment

After experiencing some minor improvements to the design, the final test was carried out over a longer time of 440 minutes to reach the target water content <0.1 %. **Fig. 7** presents the test results, and there are several specific sections of the data shown. In the dashed green line area, it can be seen that the water content of crude oil has not decreased. It is caused by the heat transfer between the hot fluid and crude oil where from the **Fig. 7** it is clearly shown both temperature difference for the hot fluid and crude oil decreased. Once the temperature difference from the heating fluid starts to rise and the temperature difference in crude oil slowly increases, the water content in crude oil begins to fall.

The anomalies phenomenon occurred at the time of 300–360 because the water content increased significantly again. The difference in the intake temperature of hot oil and crude oil continues to increase, so it is purely affected by the condition and quality of the crude oil entering the heating tank. The water content of crude oil can reach the targeted value (<0.1 %) after 370 minutes, with the difference between the working fluid and crude oil that continues to increase. It is strong evidence that the water content of the crude oil directly affected by the temperature inside the tank.

Reducing the heavy crude oil's water content through the heating process is done by modifying the storage tank into the heat exchanger. The heat exchanger is made through a simple engineering design process, and from the experiment result, the overall comparison between the storage tank (V–04) and heat exchanger tank (Free Water Knock Out) is shown in **Table 4**.

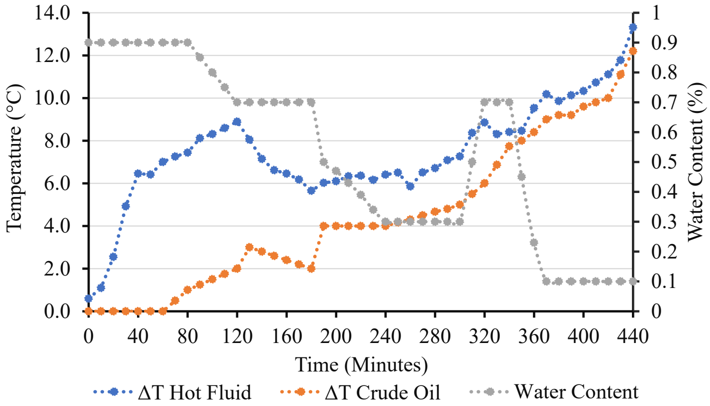


Fig. 7. Final stage experiment

Table 4
Comparison between FWKO and Tank V–04

Parameters	Free Water Knock Out V–04	Storage Tank V–04
Processing Crude Oil Quality	Crude oil with water content ≤20 %	Crude oil with water content ≤1 %
Phase fluid	2 phases (gas and liquid)	Liquid only
Contamination	Gas, oil and water	Oil and water
Working pressure	40–100 Psig	Atmospheric pressure
Working temperature	15–120 °C	50–120 °C
Standard benchmark	ASME VII (div 1)	ASME VIII/API 650
Safety equipment	Pressure relief valve	Breather valve

The FWKO has a better performance than the storage tank, especially for the phase of the processing crude oil. Furthermore, the FWKO can proceed with the heavy crude oil with a large amount of water content. By using a heat exchanger inside the tank, the water content of the oil can decrease significantly. The heat transfer fluid is heated by the gas flare, which does not make extra energy cost. The designed FWKO is acceptable for water content reduction in the oil field, particularly for heavy crude oil in an old-oil well. However, there is still some adjustment required for implementing this design under different oil well, particularly depends on the quality of the produced crude oil and the heat exchanger design for the tank. Direct measurement which conducted in this study has some deviation which implies further analysis on the heat transfer process on the storage tank. Therefore, the next improvement can be conducted through the simulation process for the energy balance on the heat exchanger and the alternative heating source for the thermic heater, such as a solar-powered heater.

4. Conclusions

The Free-Water Knock-Out method (FWKO) able to process heave crude oil with water content up to 20 %. It can be achieved with high temperature differences between the hot fluid and crude oil. The optimal temperature difference for the hot fluid is obtained at approximately 13 °C which increase the temperature of the crude oil by 12 °C. It makes the water content of the crude oil is decreased by 0.1 %. According to this result, a higher temperature difference between hot fluid and crude oil able to decrease the amount of water content on the crude oil. Also, the proposed design able to proceed the crude oil up to gas phase where it can be used for flare gas and minimizing the required energy for heating. The working pressure of FWKO is increased which helps to increase the working capacity of the processed oil. Lower working temperature is achieved by using FWKO which minimizing temperature swing between the pipe and environment for the crude oil. Better standard bench mark and safety equipment are achieved by FWKO. Further study can be taken by addressing a proper design of heat exchanger within the tank and an advanced analysis for the energy balance of the heating process which can help to reduce the operational cost and improve the reliability of the system.

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