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Research Article

Investigation of an Innovative Cleaning Method for the Vertical Oil Storage Tank by FEM Simulation

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ABSTRACT

Cleaning the huge oil storage tanks is very costly, hazardous, and time-consuming. However, this issue is one of the main concerns of the petroleum products storage industry that is performed in different ways. In this paper, an innovative oil storage tank cleaning procedure in which vertical cylindrical tanks are cleaned without entering any labor into the tank and damaging it is introduced. In this method, before filling the tank with petroleum products (i.e., oil), a sack of PVC fabric is located at the bottom of the tank, and as time passes, the heavier particles (sludge) settle on this sack. Finally, when the sack is filled with sludge, through a mechanism, it is, firstly, shifted towards the center of the tank and, secondly, lifted and taken out through the gate that exists on the roof of the tank. Thus, the above-mentioned approach not only reduces the cost of the cleaning operation but also accelerates the speed of the performed operation. To analyze the stress which is imposed on the sack's fabric by the weight of the sludge, the finite element method has been applied. The highest stress undertaken by the sack was obtained as 7.630 MPa, which, according to the mechanical properties of the investigated fabric, shows an acceptable safety factor of 1.5. In addition, the strength of the tank's walls against buckling due to the weight of the sack and sludge was investigated.

1. Introduction

In the petroleum industries before transferring liquid products to the market via pipelines or tankers, they should be stored in suitable containers to be applied at an appropriate time. In Fig. 1, a conventional vertical storage tank in which liquid fuels including oil, gasoline, petrol, and kerosene are kept for a determined period, is shown. These tanks typically have one or more inlet and outlet positioned near the bottom of the tank where the fuel is injected and extracted. Depending on the circumstances, a fixed roof as well as a floating roof, can be installed on the top of the storage tank. Oil is used in several industries to produce the final products. It is also applied to facilitate many manufacturing processes such as machining yper, finishing [4-7], metal forming, steel

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Fig. 1. Vertical storage oil tank [11].

making, and so forth. Petroleum products due to their greasy and sticky properties incline to absorb various dirt substances such as dust, oxides, and ambient particles from the atmosphere or other adjacent materials including steel pipes, rubber fittings, and so forth. In addition, the moisture of the surroundings which diffuses into the petroleum products along with organic sediments and salts forms a dens sludge depositing at the bottom of the storage tank during a particular time. This sludge not only blocks the transferring pipes but also enters the pumps and other equipment and causes extensive damage. Thus, it is necessary to prevent such damage through cleaning the tanks by evacuating the sludge. On the other hand, cleaning the tank is a time-consuming and costly operation during which the tank cannot be used for a while in order to evacuate the sludge by using workforce and related equipment. Many surveys have been conducted to reduce the cleaning operation time. For instance, Dale et al. developed a portable dispenser apparatus in 1988 which sprayed a particular solvent on the sludge surface via a hydraulic arm. Dale's device reduces the amount of time it takes to clean it, as well as the number of workers [8].

In 1989, Rowe et al. presented an optimized process to dissolve and remove the sludge by means of heating it up to a specific temperature as well as applying particular chemical materials as the catalyzer to dissolve the sludge [9].

In 1995, Krajicek and Cradeur invented an apparatus in which a rotary nozzle was installed to draw and then disperse the sludge towards the wall of the tank. In this manner, the density of the sludge decreased through agitating and mixing with the oil, and consequently, the probability of clogging the pipeline was reduced as well [10].

Reimer and Sievert designed and manufactured a special robot to collect and pump out the sludge from the storage tank that resulted in less cleaning time and cost as well as higher safety for the labors [12]. In 2010, Gopal et al. conducted a survey in which a cleaner robot was introduced and designed. The designed robot was capable of remarkably decreasing the cleaning time and increasing the efficiency and safety as well [13]. In 2009, Liu et al. published an article about application and promotion of mechanical cleaning technology in oil tanks by means of thermal purification and centrifugal separation leading to lower required time and cost [14]. In 2015, Rollins introduced an innovative device in which the operator manually cleans the sludge by utilizing steam and air nozzles and a suction pipe. In this method, the safety of the labor force increased and the operating time and cost decreased [15]. In the above-mentioned methods, the tank should be kept out of service while the dredging and cleaning operation is performed. Furthermore, the sludge particles may disperse in the oil and enter the pipeline leading to a reduction in the quality of the petroleum product.

In the present paper, an innovative method for cleaning the tank is introduced. In this method, a wide fabric sack is spread on the floor of the tank and when the sludge precipitates on it, the sack is wrapped and lifted. Therefore, the tear resistance of the sack against the weight of the sludge should be analyzed.

Stolyarov et al. investigated the mechanical behaviors of a plain weave polyester fabric, along with the consequent changes in the internal structure under uniaxial tensile loading. In their study, the engineering analysis was performed using the finite element method along with the experimental test [16]. Tessitore presented a novel finite element based approach able to represent the complex architecture of the non-crimp fabric (NCF) composite materials by means of the stiffness averaging method [17]. Page et al. introduced an FEM model for a fabric structure to predict the shear force-deformation relationship of the fabric. In their study, yarns were simulated using 3D brick elements and yarn waviness was generated by simulating the weaving process [18]. In 2021, Kantore et al. worked on a mathematical modeling of the behavior of hyper-viscoelastic particulate reinforced composite materials. They developed a three-dimensional hyper-viscoelastic constitutive equation, which includes an inherent damage parameter and its functions. Their model was used to demonstrate physical phenomenon such as the so-called dewetting effect [19]. Somarathna et al. proposed a new viscoelastic model to simulate the variation in the mechanical properties of elastomeric materials. In their study, hyper-viscoelastic constitutive models were also developed by modifying existing hyper-elastic models. They verified their models through experimental results [20]. Gudsoorkar et al. presented the simulation of the hyper-elastic property of re-treaded tire rubber with the help of finite elements (FEM). They evaluated the coefficient of hyper-elastic strain energy function by utilizing the uniaxial and planar tension test. By comparing the measured outcomes, they found that the only stable models were the Yeoh and Arruda-Boyce models [21].

As was previously mentioned, in this study, an innovative and efficient method for dredging and cleaning the vertical cylindrical tank is introduced. In this method, a wide sack is spread on the floor of the tank and when the sediments and particles precipitate on it, the sack is wrapped and lifted towards the central pivot of the tank via a mechanism including gearbox, motor, cables, and pulleys. Finally, the full sack is brought out of the tank through the ceiling gate by a proper crane. Then, another new sack is spread into the tank and the mentioned process is repeated. In this method, not only does the efficiency increase due to a substantial decrease in the operating time, but also the safety of operators considerably increases. To investigate the tear resistance of the sack against weight of the sludge, the finite element method is applied, and the obtained safety factor is checked.

2. Materials and Methods

To fabricate the mentioned sack, a flexible and high strength fabric that would withstand the weight of the sludge is required. In addition, the fabric should undertake the corrosive medium of the petroleum products. PVC fabrics have appropriate strength against tensile forces as well as proper flexibility. The PVC fabrics consist of three layers, with the middle one being coated by two PVC layers (Fig. 2). Moreover, the PVC coating contains some additives that provide unique properties to the fabrics such as UV resistance, fire resistance, corrosion resistance and antibacterial property which makes the PVC fabrics desirable for fabricating the sack [22].

According to the above-mentioned issues, the model of the PVC fabric selected for the present study is E1510 manufactured by SIOEN, a Belgian company. The chemical resistance and the specification of this fabric is demonstrated in Table 1 and Table 2, subsequently.

Fig. 2. A PVC fabric [22].

Table 1. The chemical resistance of the E1510 fabric [22]

Exposure	Rating	Exposure	Rating
Acetic acid (%5)	1	Water (salt 25%)	2
Ammoniom phosphate	1	Ammoniom hydroxide	1
Diesel	1	Ethanol	1
Antifreeze	1	Phenol	3
Benzene	3	Phenol formaldehyde	2
Kerosene	1	Sulphuric acid (50%)	1
Butanon	1	Toluene	3
Methanol	1	Nitric acid (5%)	1

1: Fluid has little or no effect
2: Fluid has minor to moderate effect
3: Fluid has severe effect

Table 2. The technical specifications of the E1510 fabric [22]

Properties	Amount	Standard of Reference
Total weight	1000 g/m^2	ASTM D751
Thickness	0.9 mm	ASTM D751
Breaking strength (warp & weft)	3500 N	ASTM D751
Breaking yield strength (warp & weft)	3000 N	ASTM D751
Bonded seam strength warp	3000 N	ASTM D751 modified by NSF 54

The simulation and finite element analysis of the collecting process of the sack has been performed using the Abaqus software. It is worth mentioning that in the present study, the behavior of the sack has the most significance, therefore, only the sack has been analyzed and the rest of the mechanism, due to their complexity and minor importance, have not been studied. Given that the sack acts as a hyper-plastic material, the anisotropic orthopedic model in the Abaqus software has been applied, in which the stress-strain relationship is derived from the strain energy density function of the material. Fig. 3 shows the elongation percentage of the applied fabrics by imposing 2000 N per meter during 100 hours according to the catalogue of the manufacturer company [22].

In the properties modules in Abaqus software, the hyper-elastic model according to Arruda-Boyce's equation and the equation of the state Us-Up are applied [23] for the sack and for the precipitation (sludge) respectively. Furthermore, the equation of the state is a thermodynamic kind that indicates the different states of the material by considering their temperature, pressure,

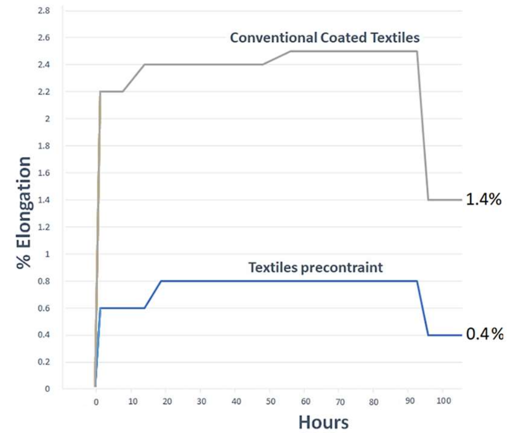

Fig. 3. Elongation percentage of the applied fabrics by imposing 2000 N per meter [22].

and volume. For sediments precipitating at the bottom of the sack, Us-Up equation (linear relation equation between momentum and particle velocity) has been applied.

Due to the weight of the full sack and other mechanical components imposing on the top of the tank, the buckling occurrence through the wall of the reservoir has been investigated as well. For this purpose, the wall has a 10 mm thickness and is made of steel St37 with 235 MPa yield strength.

In the properties module of Abaqus software, the following properties have been designated for the sack: dynamic viscosity: 0.001145 Pa.s, Material type: isotropic, strain energy potential: Arruda-Boyce with the coefficient of 300000 μ and 1.01 λ_M [23]. In addition, for the sludge, the Us-Up type have been set for the equation of state with 1450 for C_0 parameter and zero for γ_0. Moreover, the Newtonian viscosity with 0.001145 Pa.s dynamic viscosity have been defined as the material behaviour of the percipitation.

In the assembly module, the parts are assembled and the sludge is located on the fabrics while the fabrics are located on the bottom of the tank. At the interaction module, general contact and self-contact are applied to define the contact among parts. Finally, the boundary conditions and gravity are applied for the model. In Fig. 4, the meshed sack, the assembly of the sludge on the sack and the interaction between the sack and the sludge is demonstrated.

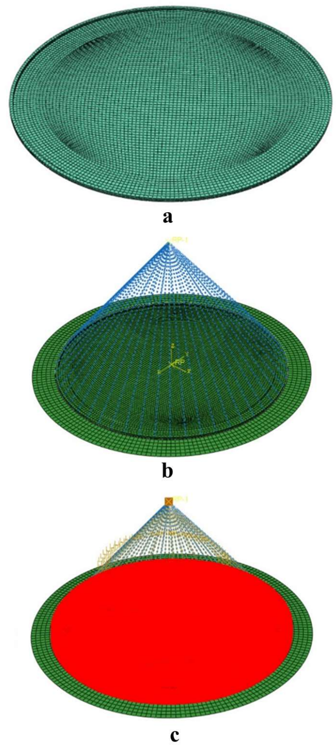

Fig. 4. (a) Meshed sack, (b) assembly of sludge on sack, and (c) interaction between sack and sludge.

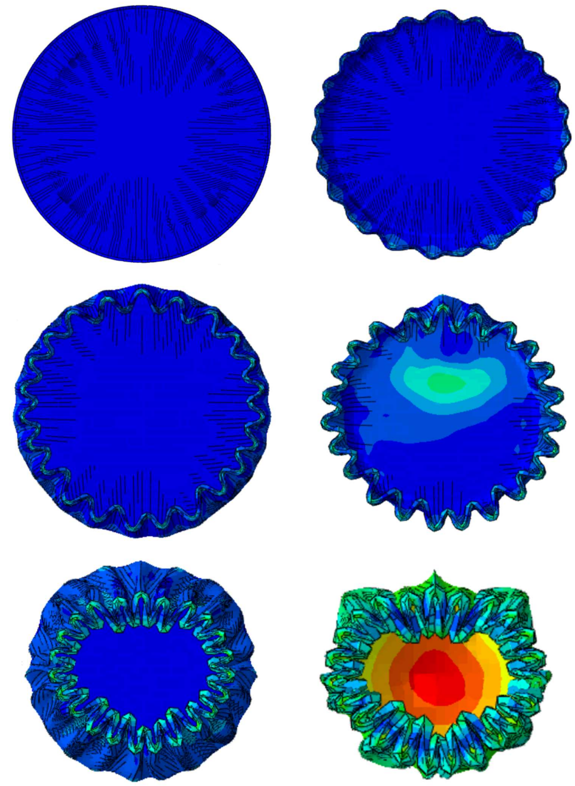

Fig. 5. Closing stages of the sack.

3. Results and Discussion

Fig. 5 shows the simulation of closing stages of the sack from the top view. According to Fig. 5, the steps of the packing of the sack, including wrinkling the whole body and the top of the sack, are clearly demonstrated.

The stress distribution diagram with von Mises criterion is shown in Fig. 6 and the contact stress distribution diagram in the sack is shown in Fig. 7. The maximum tensile stress happened at the bottom of the sack due to the weight of the sludge. This stress is equal to 7.630 MPa which is less than the yield strength of the sack fabric (11 MPa). Fig. 8 shows the strain distribution in the sack. The maximum strain in the sack happens at the bottom of the sack and is equal to 0.42. In addition, the safety factor of the sack's fabric is calculated at approximately 1.5, which is acceptable. However, to increase the safety factor and to prevent tearing in the high stress regions of the sack, using the fabric, which is reinforced with the steel wires as shown in Fig. 9, is suggested.

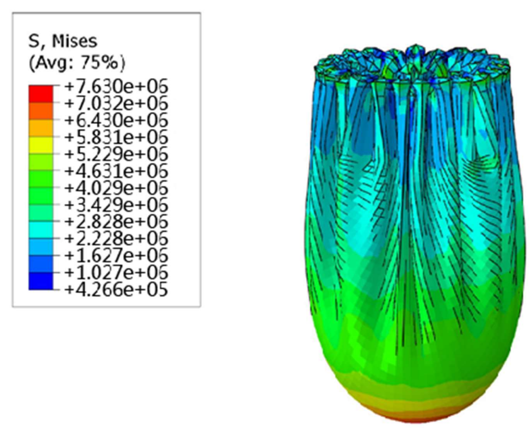

Fig. 6. Stress distribution in the sack.

The deformation of the wall caused by the weight of the sack and its accessories is shown in Fig. 10. The maximum deformation occurred at the upper edge of the tank and is equal to 1.15mm, which in comparison with the whole size of the tank, is negligible. Moreover, by imposing this amount of force on the ceiling of the tank no buckling phenomenon was reported by the software.

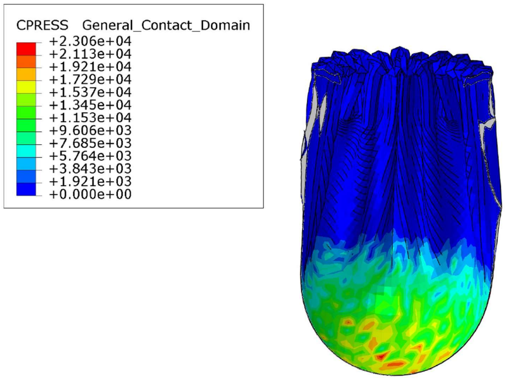

Fig. 7. Contact stress distribution in the sack.

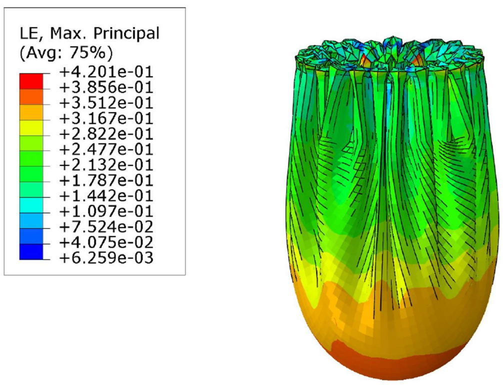

Fig. 8. strain distribution in the sack.

Fig. 9. Fabric reinforced with steel wires [22].

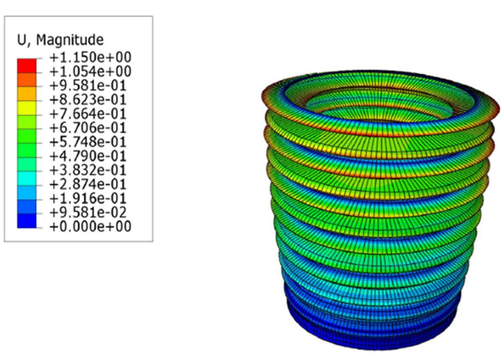

Fig. 10. Tank deformation through the buckling test.

4. Conclusion

In this study, an innovative and efficient method for dredging and cleaning the vertical cylindrical tank is introduced. In this method, a wide sack made of a special fabric is spread on the floor of the tank and when the sediments and particles precipitate on it, the sack is wrapped and lifted towards the central pivot of the tank via a mechanism. Finally, the full sack is brought out of the tank through the ceiling gate. In this novel method, the operating time substantially decreases. To investigate the tear resistance of the sack against the weight of the sludge, FEM simulation has been applied and the results are as follows:

- The maximum tensile stress through the sack fabric was obtained 7.6 MPa via the Abaqus software which is less than the yield strength of the sack fabric (11 MPa).
- The safety factor was approximately calculated at 1.5 as well. To increase the safety factor and decrease the stresses of the sack, it is possible to reduce the amount of the sludge by decreasing the cleaning service period. In addition, by applying the reinforced fabric beside the PVC fabric, the yield strength of the sack noticeably increases.
- The points of the sack which is the location of passing the rope and cable are critical and by applying multilayer fabrics in these points, the stress can be relieved.
- According to the finite element analysis of the software, the buckling phenomenon does not occur through the wall of the tank and the maximum deformation is reported to 1.5 mm, which is negligible.
- To use this cleaning method for larger diameter tanks, due to an increase in sludge weigh, two or more separate sacks, all of which cover the entire floor of the tank, can be applied.

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Conflict of Interests

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