DESIGN ANALYSIS AND MODIFICATION OF COMBINED DEAERATOR-THERMAL BUFFER TANKS FOR PROCESS USING THERMIC FLUID

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Abstract - Due to increasing trend of adopting thermal oil as heat transfer fluid in variety of processes, the service life and ability to transport the required thermal energy to the process become the important factor to ensure the system performance. So far, the quality of such heat transfer fluids had been developed quite satisfactory but the operational problems could be emerged typically from the improper design of related expansion tank system and/or operational procedures. This research so aimed to investigate the hydrodynamics and heat transfer behavior of the thermal oil within the expansion tank system comprising of the deaerator-thermal buffer tanks and upper storage expansion tank. Also, the influence of modification of shape or aspect ratio of such tanks on the oil temperature when exposing to air was studied. A commercial (Fulton) expansion tank system was adopted as the prototype and created as the finite-element computational domain for such purposes. Under average practical operating condition, the thermal oil i.e. Therminol®66 at 140˚C with flow velocity of 3 m/s was applied as generic case of the investigation. The simulation results showed that the combined tanks with smallest diameter i.e. -40% reduction exhibited the lowest thermal oil temperature that less than 40˚C while all the cases also kept the oil temperature below the recommended value of 50˚C.

Keywords - Thermal oil system, Expansion tank, Thermal buffer tank, Oxidation degradation

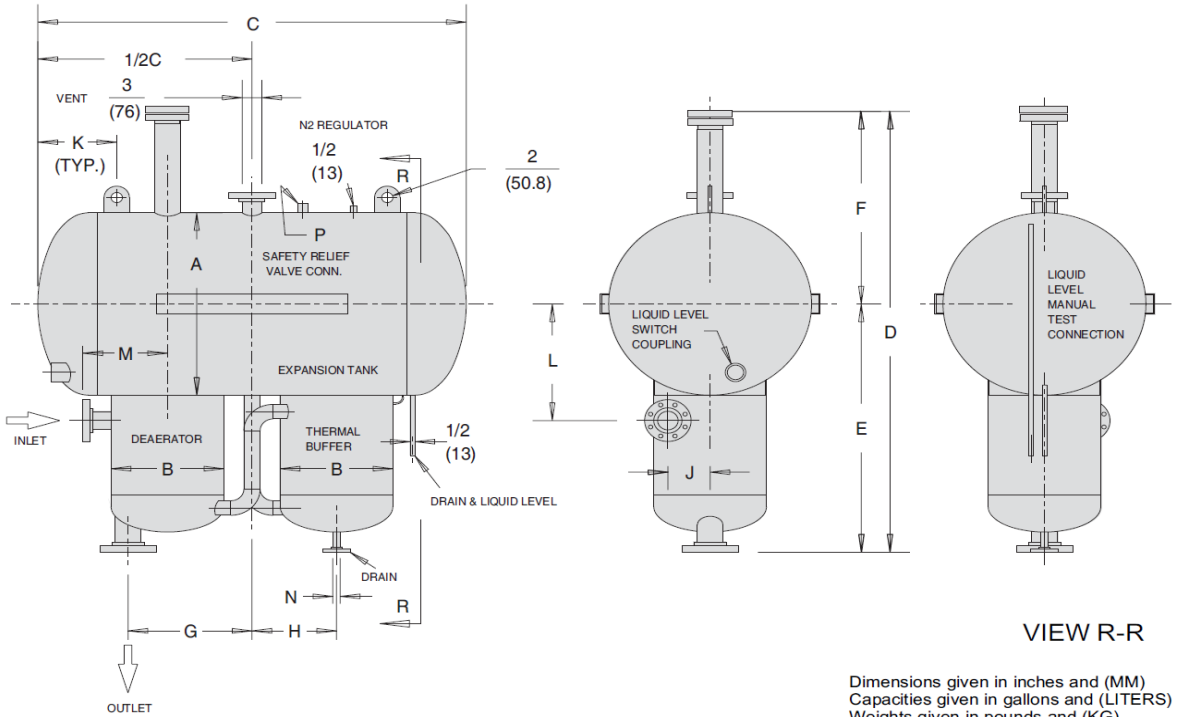
I. INTRODUCTION

Various manufacturing processes usually need to elevate the temperature of raw materials, working fluid or system atmosphere to the value much higher than that of the normal atmosphere. The applications may involve heating of chemicals in a reactor, melting of chemicals or substances etc. Many conventional heating methods ranging from electrical heating, steam or hot water heating to direct flame or hot flue gases heating are often adopted so far. For widely used steam system, certain difficulties or limitations of application can arise such as high risk of overpressure and explosion leading to requirement of very strong and expensive structure especially for extremely high temperature and pressure. For such severely high temperature, a heating system employing thermal fluid as a transfer media instead of steam becomes an interesting alternative.

Generally, for thermal oil heating process, the heat transfer fluid will pick up heat from a thermic heater to raise the fluid temperature and circulate through pipelines and heat consumer units like heat exchanger, drier, reactor etc. Among various types of thermal transfer fluids commercially available nowadays, the applicable range of temperature can be as high as 280 ˚C for petroleum-based (mineral) media, 350 ˚C for synthetic media, and 400 ˚C for synthetic vapor phase media. Although, using the thermal transfer fluid in lieu of steam offers some advantages especially an operational safety due to low pressure condition, the system requires certain operation unit for handling the expansion and contraction of thermic fluid duringheating and cooling, respectively. Thus, in order to accommodate such phenomena, the thermal fluid system design requires to have the expansion tankwhere the thermal fluid can expose to surrounding air (open system) or an inert gas like nitrogen (closed system). The former type of system is suitable for the lower applied temperature as compared to the closed system in order to avoid an unintentional degradation of the thermal oil.

The expansion tank, especially for the open system type, must be designed and selected properly for the range of process temperature of interest.In spite of an economical advantage, the open type expansion tank will have more chance of an oxidation degradation of the thermal oil due to the exposure of high temperature oil with penetrating air. Once the degradation set in,the properties of oil will change, for instance, reduced thermal conductivity and increased acidity causing damage to parts and/or equipment and upsetting or even totally disrupting the system.

Therefore, the main objective of this study is to investigate the hydrodynamics and thermal conditions of the thermal oil within a commercial expansion tank system and modify such design to improve the system performance. In doing that, the finite-element models of the open-type expansion tank system is developed. Among the output parameters, the temperature of thermal oil in the expansion tank will be evaluated and analyzed.



MODEL	A	B	C	D	E	F	G (Ref)	H	J (Ref)	K	L	M	N	P
FT-2000-L	42 (1070)	22 (560)	106 (2690)	107 ⅝ (2734)	62½ (1590)	45 ⅛ (1146)	31 3/16 (792)	24 (610)	8 ½ (216)	15½ (394)	28 (710)	14 15/16 (379)	1 (25)	1½ (38)

Fig1. Key dimensions of the of Fulton's expansion tank system

II. SIMULATION DESCRIPTIONS

2.1. Computational Models

In this research, the expansion tank equipped with the combined deaerator-thermal buffer system was modeled and the finite-element scheme was applied in order to simulate the flow field and involved heat transfer of the thermal fluid system. Fulton's FL-2000L as a prototype of expansion tank set was studied. Prominent dimensions of FL-2000L model were summarized in Fig1. Assumably, under steady state operation and practice, the oil level once expanded will be at 3/4 height of the top expansion tank.

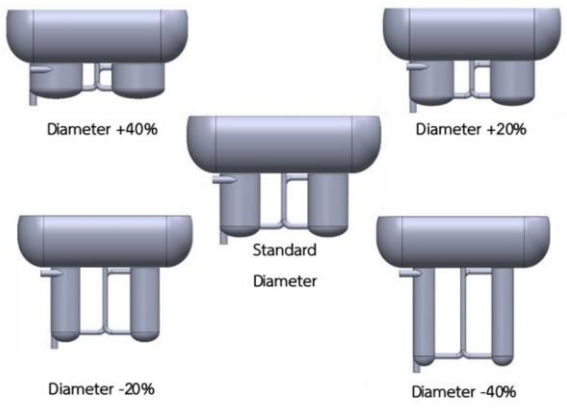


Fig2. Modified deaerator-buffer tanks models

To investigate the efficiency and the effect of aspect ratio of combined tanks, the diameters of the deaerator and buffer tanks of FL-2000L were adjusted by ±40% while maintaining the heat transfer effective area. As a result, the heights of the deaerator-thermal buffer tanks were rearranged as illustrated in Fig2.

2.2. Governing Equations

The computational models of expansion tank system were developed in the finite-element scheme (COMSOL Multiphysics 3.5a) under the same operating conditions. For the simulation of flow and heat transfer, the Turbulent Non-Isothermal Flowand Steady State Analysis modules were selected. The three-dimensional flow field was obtained by solving the related conservation equations i.e. the steady state Incompressible Navier – Stokes as shown in Eq1.

$$\rho\frac{\partial \boldsymbol{u}}{\partial t}-\nabla\cdot\eta\left(\nabla\boldsymbol{u}+(\nabla\boldsymbol{u})^{\mathrm{T}}\right)+\rho(\boldsymbol{u}\nabla)\boldsymbol{u}+\nabla p=0 \quad (1)$$
$$\nabla\cdot\boldsymbol{u}=0$$

where η = dynamic viscosity, u = velocity vector, ρ = fluid density, and p = fluid pressure.

The energy equation in terms of temperature coupled with the hydrodynamics (kinetic and flow energies) of the fluid was indicated in Eq2.

where T = fluid temperature, C_p = fluid heat capacity, k = fluid thermal conductivity, and Q = heat source. The governing equations i.e. Eq 1. and Eq 2. were discretized and solved numerically to provide the results in terms of the hydrodynamics and thermal parameters.

In subdomain setting, the physical and transport properties of heat transfer fluid were based on those of Therminol®66 (synthetic type). In boundary condition setting, the inlet velocity of heat transfer fluid was set at 3 m/s (operation recommended value). The outlet conditions were set as an atmosphericpressure. All wall boundaries were set as No-Slip boundary conditions. In thermal boundary condition setting, the inlet temperature was set at 140˚C and neutral at the outlets. The wall was set as natural convection heat flux to the ambient temperature of 30˚C.

III. RESULTS AND DISCUSSION

3.1. Hydrodynamics of thermal fluid

As presented in Fig 3., the CFD analysis with resulting flow field of the prototype FL-2000L indicated the apparent swirl flow of the thermal fluid along the downward axial direction of the deaerator tank. Mainly, the flow velocity oriented tangentially and higher on the outer radius as compared to that of the center core. The magnitude of oil velocity was displayed by colored-contour streamlines and the corresponding flow direction was indicated by the (red) velocity vectors. On the other hand, the thermal oil in the buffer tank did not exhibit any particular flow pattern but nearly stagnant.

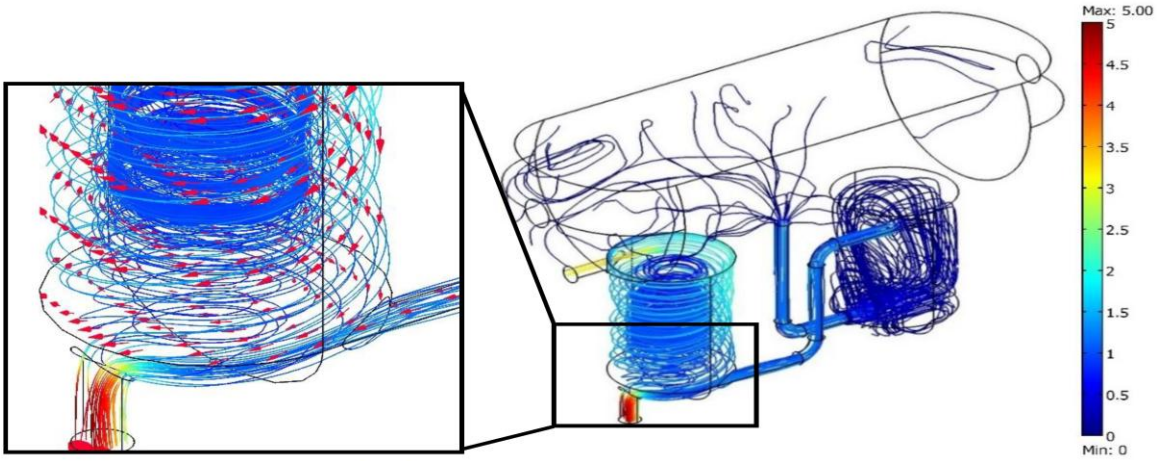


Fig3. Flow field of the thermal transfer fluid in the prototype expansion system

$$\rho C_p\left(\frac{\partial T}{\partial t}+u\nabla T\right)=\nabla\cdot(k\nabla T)+Q \qquad (2)$$

From a continuity of flow, the flowrate of the under-flow outlet counterbalanced with the inlet flowrate and a very small flow of the buffer tank (from potential energy in the expansion tank). Because of the strong tangential flow in the deaerator tank, the convection mechanism of the oil side was expected to be more pronounced as compared to that of the buffer tank.

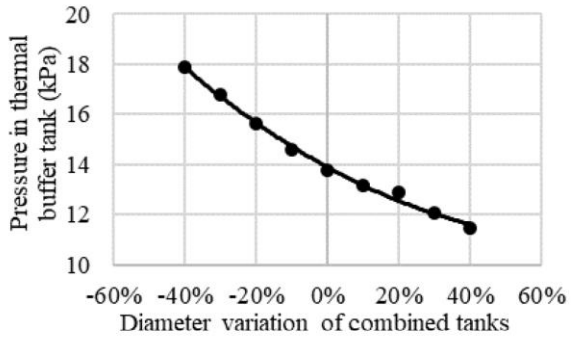


Fig4.Pressure in the thermal buffer tank

In Fig 4., the resultant oil pressure in the vicinity of buffer tank inlet was highest for the case of 40% diameter reduction due to the hydrostatic pressure field. This high-pressure region hindered the thermal oil flowing from the deaerator tank to enter the thermal buffer tank and so the most part of the thermal oil flew pass through the underflow outlet of the deaerator tank. The amount of outflow oil and thus the flow velocity were resulted by the corresponding balance of mass flow of oil as illustrated in Fig 5.

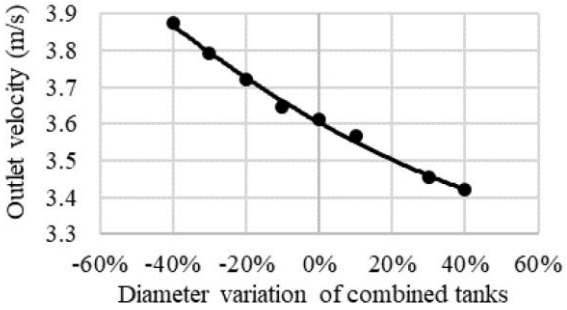


Fig5.Average velocity at the underflow outlet of deaerator tank

3.2. Temperature Distributions

In consequence of the swirl flow field in the deaerator tank as mentioned previously, the induced forced convection on the thermal oil side enhanced the overall heat transfer and caused the thermal oil to dissipate effectively. As a result, the temperature of oil declined from the high inlet temperature to the lower outlet temperature. More importantly, the temperature at the inlet of the thermal buffer tank was reduced significantly by one order of magnitude as shown in Fig 6.

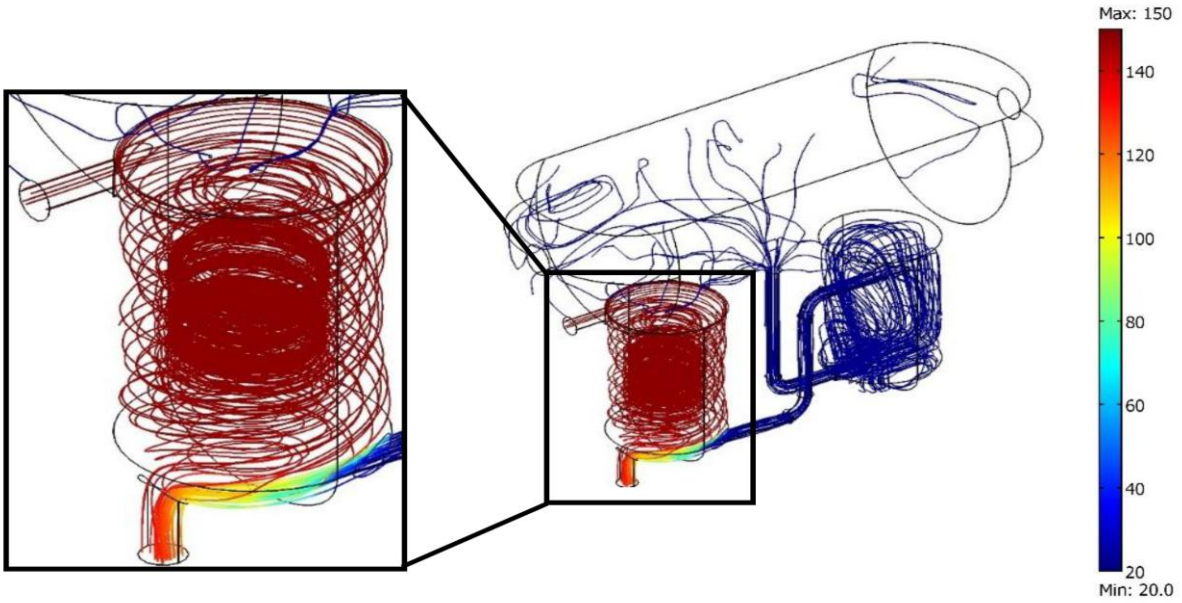


Fig.6. Temperature flow field of the thermal transfer fluid in the prototype expansion system

Since a majority of heat was removed from the thermal fluid in the first tank due to the strong induced spiral flow, the fluid with much lower thermal energy and flow energy gradually transported to the next buffer tank and the above expansion tank, respectively. From the practical operation point of view, the average thermal oil temperature was found to be about 30˚C (recommended value of 50˚C and not to exceed the maximum of 60˚C), which was considered a safe temperature against oxidation when exposed to air. Thus, Fulton's combined expansion tanks system were suitable and functional in this regard.

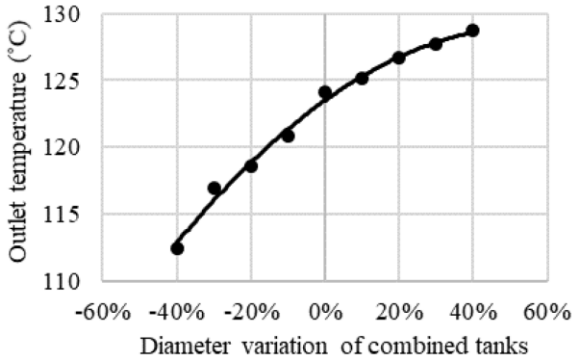


Fig 7.Average temperature at the underflow outlet of deaerator tank

The influence of the shape or aspect ratio of combined deaerator-thermal buffer tanks was observed in Fig 7 through Fig 9. For smaller diameter and slender tanks, the outlet velocity was higher but the resultant outlet temperature of oil was lower (Fig 7); nevertheless, the enthalpy of outflow thermal oil was the highest as figured in Fig 8.

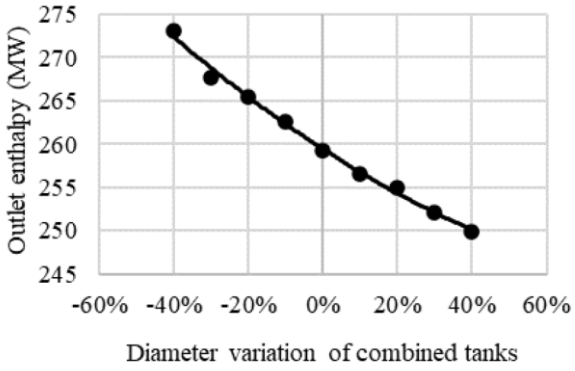


Fig 8.Enthalpy at the underflow outlet of deaerator tank

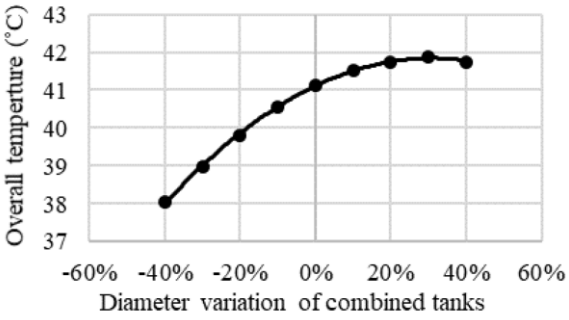


Fig 9.Overall temperature of thermal oil within the combined expansion tanks

Fig 9. exhibited the average temperature of the thermal oil within the combined tanks system for each configuration. Since the outlet enthalpy trended to decrease for the larger value of tank diameter, the temperature of oil within the system trended to be higher. Above all, from the operation stand point, all configurations considered in this study provided the effective mean of controlling the thermal oil temperature to avoid a likely oxidized condition.

IV. CONCLUSIONS

In the present study, the flow dynamics and thermal behavior of heat transfer oil in certain expansion tank configurations were investigated and major conclusions could be drawn as following:

- The swirl flow field in the deaerator tank played a vital role in reducing the oil temperature by an order of magnitude.
- The mechanism for preventing high temperature oil coming into contact with air is the resultant pressure of oil inside the upper part of the expansion tank.
- Increasing the tank diameterslowered the amount of heat dissipation and resulted in higher oil temperature.

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