Experimental Enhancement of the Steam Quality Using Water Based Nanofluid (Al_2o_3)

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Abstract

By the expansion process in a throttle valve, the heat transfer at the solid-fluid interface affects the thermal state of the fluid (steam) passing through it. In this expansion process, the steam loses the heat and converts to water vapor by the addition of the moisture content. Here, the quality of the steam is important at the point of next to expansion. The quality of the steam is increased by adding the nanoparticles. Since nanofluids are shown the capability of transmitting heat more than the conventional fluids which could be useful in many applications, the experimental analysis is done to determine the dryness fraction of the steam using water-based nanofluid Al_2O_3 with different concentrations 0.1%, 0.2% and 0.3% in separating throttling calorimeter. Numerical calculation for enhancing the heat carrying capacity in the expansion process through the throttling is done by considering the steady and turbulent k-ε model with a constant Reynolds number for the different concentrations of nano-fluids. The dryness fraction is 0.96 for water-based nanofluid Al_2O_3 with 0.3% concentration as compared with water of 0.83 dries.

Key Words: Throttling, Nanoparticles, Dryness fraction, Steam

I.INTRODUCTION:

In power plants generating electricity, the condition of the steam is crucial for efficient energy conversion. The turbine relies on steam to perform work, and if the steam is in a wet state, it can negatively impact both the efficiency of heat energy conversion and the turbine's components. Figure 1 illustrates a system consisting of a separating calorimeter and a throttling calorimeter connected in series to measure steam quality. The separating calorimeter removes the wet portion of the steam, and the remaining dry steam flows into the throttling calorimeter, where it undergoes expansion.

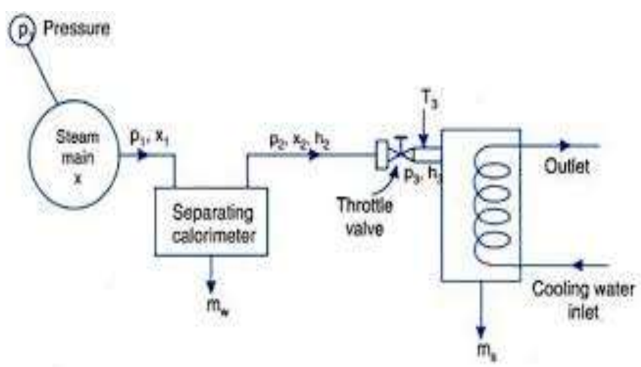


Fig. 1 Separating and Throttling Calorimeter

In a thermal power laboratory, an experiment was carried out to measure steam quality using Separating and Throttling Calorimeters, while also evaluating the impact of temperature and pressure on steam properties [1]. Additionally, numerical simulations were conducted for laminar flow in a channel, incorporating nanoparticles in fuel-oil and water-based fluids. The simulations employed the SIMPLE algorithm for pressure-velocity coupling [2]. The thermal conductivity of a 13nm Al_2O_3 water-based nanofluid solution was measured at various volume fractions [3]. The study found a 40% increase in thermal conductivity for Cu oil-based nanofluids at a 0.3% volume concentration, while Al_2O_3 water-based nanofluids showed a 29% improvement in thermal conductivity at a 5% volume concentration [4]. Larger particles in the fluid can lead to several disadvantages, including negative effects on the thermal properties of the fluid and wear on system components. To address these challenges, nanoparticles smaller than 100nm are mixed with base fluids such as water [5-6].

Nomenclature

C_p	Specific heat at constant pressure in KJ/Kg-K
φ	Concentration of Nano particles in %
ρ	Density in Kg/m^3
f	Base fluid
np	Nano particles
nf	Nanofluid
X	Dryness fraction
W	Amount of water collected

II.EXPERIMENTAL SETUP

Different types of steam measuring devices are there like, separating calorimeter, throttling calorimeter and combination of those two. These calorimeters are used increasing the quality of steam by using different variations of nanofluid. The calorimeter is the measure of the thermal energy that is transferred from one object to another when they come in contact due to a difference in temperature. Throttling calorimeter uses the principle of constant expansion of the enthalpy to measure the water content in the vapor.

The nano particles were purchased from and prepared Nano fluids at NANO WINGS PRIVATE LIMITED and the properties are given in Table 1.

TABLE 1 PROPERTIES OF NANOPARTICLES

Parameter	NANO ALUMINA(Al_2O_3)
Appearance	White powder
Crystallite size	10-20 nm (PXRD)
Purity	99%
Bulk density	0.2-0.4g/cm^3
Density	3890 kg/m^3

By using two step method, Al_2O_3 nanofluid with water as base fluid was prepared. The powder nano particles are purchased from Nano wings pvt ltd with 99 % purity. By volume percentages which are 0.1:99.9, 0.2:99.8 and 0.3:99.7, the fluid was prepared.

III.THERMAL PROPERTIES

In the point of thermal behavior of a fluid, it is important to know about the properties like, density, specific heat, viscosity, thermal conductivity, and dryness fraction.

$$\rho_{nf} = (1-\varphi)\, \rho_f + \varphi\, \rho_{np} \qquad (1)$$

$$(C_p)_{nf} = \frac{(1-\varphi)(\rho Cp)f+\varphi(\rho Cp)p}{\rho nf} \qquad (2)$$

The properties density and specific heat of the nanofluid with water are calculated by using Eqn (1) and Eqn (2). Thermal conductivity of the fluids calculated by experiment that to be done with the help of Nano Wings Pvt. Ltd. and are tabulated in Table 2.

TABLE 2 PROPERTIES OF AL_2O_3 WATER BASED NANOFLUID.

	Concentration (volume percentage of Al_2O_3)	Density (kg/m^3)	Specific heat (J/kg-K)	Thermal conductivity (W/m-K)
Water	0	998	4182	0.597
Distilled water	0	998	4182	0.6
Water +Al_2O_3	0.1	1001.08	4168.55	0.614
	0.2	1003.96	4155.19	0.63
	0.3	1006.85	4141.88	0.648

Measuring of the quality of the steam was done by the experiment separating and throttling calorimeter, in which, the steam was heated by the electrical to a pressure of 1 bar and was allowed flow through the pipes connected to separating calorimeter to separate moisture content and next to throttling calorimeter where expansion without work was takes place. Then, it allowed through condenser to collect the dry steam content in throttling calorimeter. For the calculations, the observations of temperature and pressure were taken at the inlet of separating and throttling calorimeters. The content of liquid collected from separating and throttling calorimeters were also measured, and all the readings were tabulated.

Fig. 1.2.1 Experimental setup of Separating and Throttling Calorimeter

IV.OBSERVATIONS

The experimental results demonstrated expected variations in the dryness fraction, reflecting the influence of different conditions. Additionally, significant changes were observed in the enthalpy, entropy, and thermal conductivity, consistent with the anticipated trends. These results indicate that the modifications made to the steam system, including the introduction of nanofluids, effectively impacted key thermodynamic properties. The observed variations align with theoretical expectations, confirming that the experimental setup was successful in measuring the performance of the steam system under different conditions. This further supports the potential for using these methods to optimize steam quality and thermal efficiency.

TABLE 3 OBSERVATION TABLE FROM THE EXPERIMENT

	Concentration (volume percentage of Al_2O_3)	Pressure inside the separating calorimeter (P1)kg/cm^2	Pressure inside the throttling calorimeter (P2) kg/cm^2	Temperature of the steam at the inlet (T1) ^{0}C	Temperature of the steam after throttling (T2) ^{0}C	Volume of water collected from the separating calorimeter (w) ml	Volume of condensed water collected from the condenser (ws) ml
Water	0	0.79	0.712	96.405	90.33	100	20
Distilled water	0	0.79	0.7354	96.405	91.01	98	17
Water + Al_2O_3	0.1	0.79	0.74	96.405	91.43	91	16
	0.2	0.79	0.761	96.405	92.16	89	15
	0.3	0.79	0.78	96.405	92.83	86	15

V.CALCULATIONS

Assumption taken that the steam formed from the nano-fluid is having the properties of normal steam as the nanoparticles were less concentration and dispersed in fluid while formation of the steam. The properties of steam were taken from the steam tables at the temperatures P_1, P_2, T_1, and T_2. By using the same, the values were calculated for the nano-fluid at different concentrations of 0.1, 0.2 and 0.3 percentages by using the formulae:

Dryness fraction for separating calorimeter $X_1 = W_S / (W_S+W)$

Dryness fraction for throttling calorimeter $X_2= [H_2 + C_p (T_2-T_s) – H_1]/ L_1$

Actual dryness fraction for combined throttling calorimeter $X= X_1 \times X_2$

Enthalpy for combined throttling calorimeter $H= h_f +X (h_{fg})$

Entropy for combined throttling calorimeter $S= S_f +X (S_{fg})$

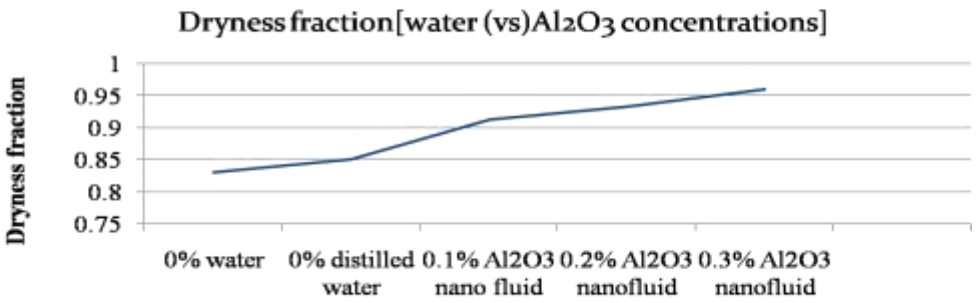
VI.RESULTS

From the calculations, the values of dryness fraction, enthalpy, and entropy values of the water without nanoparticles addition, distilled water, and water with nanoparticles addition of 0.1%, 0.2% and 0.3% are tabulated in Table 4.

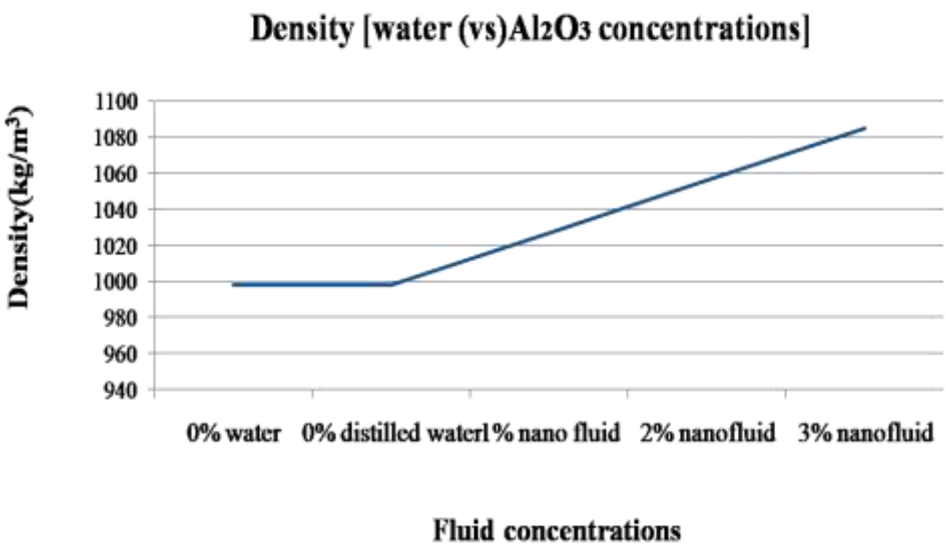
TABLE 4 ENTHALPY, ENTROPY, THERMAL CONDUCTIVITY AND DRYNESS FRACTION VALUES FOR FLUID WITH NANOPARTICLES OF DIFFERENT CONCENTRATIONS

Concentration (%) / Properties	Water (0% Al_2O_3)	Distilled water (0% Al_2O_3)	Water + Al_2O_3 (0.1%)	Water + Al_2O_3 (0.2%)	Water + Al_2O_3 (0.3%)
Dryness fraction	0.83	0.85	0.912	0.933	0.96
Enthalpy in kJ/kg	2285.05	2330.38	2470.9	2518.49	2579.69
Entropy in kJ/kg K	6.405	6.526	6.919	7.03	7.19

From the observation table it was observed that the temperature drops during expansion process of steam increases with increase in the concentration of the nano-fluid. That indicates that the amount of heat gained by the steam was also increases with addition of the nano particles. So, it can easily able to reach the supersaturated and superheated state easily for the same heat input.



Graph 1 Dryness fraction vs Concentration of the fluid



Graph 2 Density vs Concentration of fluid

VII.CONCLUSION

Experimental and numerical calculations of steam through throttling calorimeter were performed with nano-particle addition. At different concentrations, thermal behavior of the steam is analyzed with constant heat input. The main conclusions are summarized as

1. Dryness fraction increased by 13.54% as addition of nanoparticles of 0.3% Concentration in water.
2. Enthalpy increased 11.42% for the same heat input.
3. Entropy increased by 10.92% for water with 0.3% Concentration Al_2O_3 Nanofluid
4. Thermal conductivity increased 7.9% for water with 0.3% Concentration Al_2O_3 Nanofluid.

VIII.ACKNOWLEDGEMENT

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