Preparation of Nanofluids through Two-Step Method: Novel automation approach

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***Abstract*— The two-step method is a popular approach to preparing nanofluids in research centers, mainly due to its cheap costs and simplicity. The method is done by acquiring nanomaterial and then mixing them with a base fluid using a sonication device. Dispersants are added to the process to improve the mixing and solution quality and stability. However, the time required by researchers to perform mixing, human errors associated with the mixing process leads to inconsistencies in the research findings. This paper offers a novel approach to simplify the mixing process for researchers to carry out nanofluid preparation easily. The approach is to carry out the process using a nanofluid vending machine. The machine is mainly comprised of an MCU controller, a sonication container, several storage containers for different nanomaterials and solenoid valves to facilitate the mixing process. Load cells, temperature sensor and a timer are used to monitor the amount of nanomaterial and base fluids, mixing temperature and period, respectively.**

***Index Terms*— Two-step method; dispersant; vending machine; Nanofluids**

I. Introduction

Nanofluids are fluids with better thermophysical properties which can be used for a variety of heat transfer applications. Research in the area of nanofluids is comprehensive and rapid. Researchers in many research facilities use the two-step method to create nanofluids for desired applications. The two-step method is carried out by first acquiring nanomaterial in powder form and selecting a suitable base fluid. The nanomaterial and base fluid are mixed at desired proportions to yield the desired nanofluid [1-2]. Volume fractions (%) of nanofluids are commonly tested to find the optimum volume fraction for the heat transfer application. Equations (1) describes the volume fraction of the nanofluid [3]:

$$\text{Volume fraction (\%)} = \left(\frac{W_{np}/\rho_{np}}{W_{np}/\rho_{np} + W_{bf}/\rho_{bf}} \right) \quad (1)$$

Where Wnp and Wbf are the weights in grams of the nanoparticle (or nano-powder) and base fluid, respectively.

Researchers often decide the volume fraction needed and derive the corresponding nanomaterial weight in grams. A dispersant is added, and the nanomaterial are directly mixed with base fluid to create the nanofluid [4]. The mixing is carried out using ultrasonication. Commonly a sonication probe is used to perform the sonication, while some studies employ sonication bath instead. Figure 1 illustrates the two-step method.

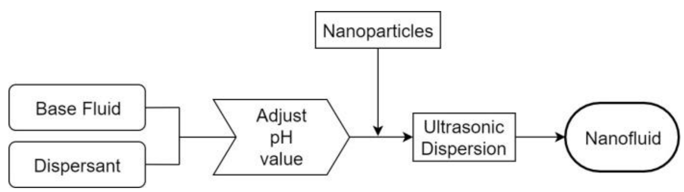

Figure 1. The two-step method

Although the approach is relatively simple and cheap, it requires careful exercise to avoid discrepancies. The dispersant is added to the process to modify the surface of the particle in order to prevent their aggregation [5], a common example of surfactant is CTAB [6-8]. Nakayama and Hayashi [9] used an organic liquid and TiO_2 nanoparticles, and modified the surface using propionic acid and n-hexylamine. Surface modification was found to improve the dispersion of the nanofluid. Mechanical agitation, ultrasonic waves and other physical means are commonly used to break the particle agglomeration [10-11]. Hence, the two-step method may employ various equipment and strategies and eventually the mixing process requires precise measurements of the material quantities, to be employed. Hence, discrepancies in the yielded nanofluids may arise [12]. This article proposes a nanofluid vending machine which can reduce the issues associated with the two-step method and ease the process of nanofluid large-scale production. Chew et al. [13] dispersed DBSA-doped PANI nanoparticles in deionoized water to develop polymer nanofluids, fixing the weight percentage of nanoparticles at around 0.2%-1%. The physical mixing was carried out using an ultrasonic bath for eight hours and adjusting water pH to 8 using 0.1 M NaOH. The study concludes that doping 1% of DBSA-doped PANI nanoparticles in water lead to enhancement in its thermal conductivity by 5.4%. Drazazga et al. [14] prepared metal oxide – water nanofluids, CuO and Al2O3 and tested their stability after using stabilizers. The researchers used ultrasonic mixer and a full day. For the case of CuO, SHMP stabilizer was added to the samples with concentrations 0.1%, 0.2% and 0.3%. For case of Al2O3, acetic acid and SHMP were investigated, being added to different samples and in different combinations. 0.1% mass of SHMP in CuO led to obtaining good CuO-water nanofluid stability. Poor stability was observed for all cases of Al2O3 and was attributed to average size of particle which may not be enough for deagglomeration via sonication. Duangthongsuk and Wongwises [15] dispersed TiO2 nanoparticles in water, which was also mixed with surfactant. An ultrasonic vibrator was used for a sonication of 3-4 hours and researchers observed little agglomeration after 3 hours.

II. Novel Automation Approach

The novel approach is to create a nanofluid vending machine which facilitates the mixing process of selected nanomaterial and base fluids and of quantities corresponding to the desired volume fraction (%). The main features this machine offers are:

1. Mix nanofluids at desired volume fractions (%).
2. Vending the nanofluids into user's nanofluid-sample container.
3. Rinsing the mixer container.

The machine consists of an MCU controller, several storage containers, several solenoid valves, load cell sensors for weight measurement, a timer, temperature sensor, a sonicator transducer and a heater. The conceptual design of the machine is illustrated in figure 1.

The mixing process occurs at the mixer container and in its heat is applied as well to produce the desired nanofluid. Once the process is complete, the nanofluid is poured onto the nanofluid-sample container.

Vending machines are traditionally used to dispense goods products, beverages and snacks [16]. These machines are cost-effective goods distribution systems which can operate automatically [17-18]. Modern vending machines are designed using FPGA [19-20], user-input technology, processing unit, communication program, memory, interface technology [21], controller, control module, heating/cooling unit and solenoids [22], etc.

The proposed nanofluid vending machine can be used to produce nanofluids for scientists and end-users for heat transfer applications [23] such as nanofluid-based solar thermal collectors [24], nanofluid-based PV/T collectors [25] and nanofluid cooled electronic devices [26], etc.

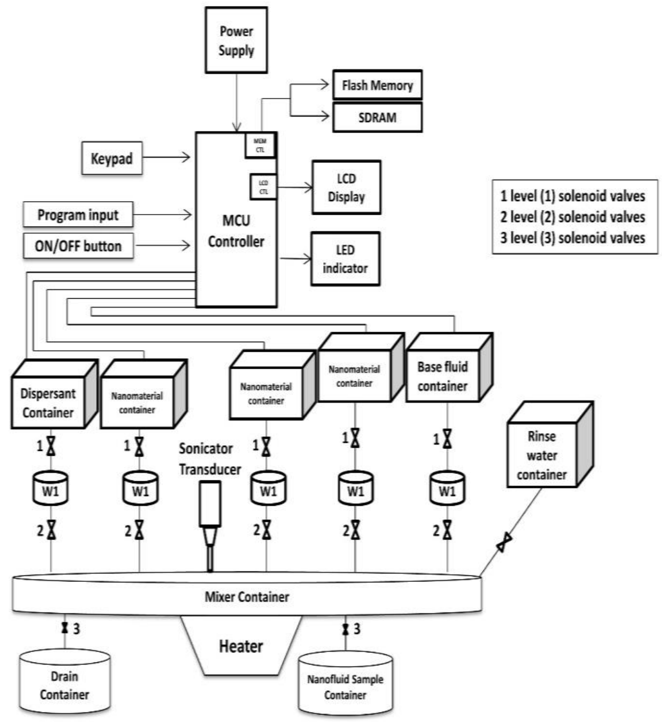

Figure 2. Conceptual design of the machine

The block diagram of the MCU-controller is provided in figure 3. The main inputs to the controller are the power supply, program input, keypad, temperature sensor, load cell sensors and timer. While the outputs of the MCU-controller are the LCD display, LED indicator, solenoid valves, sonicator transducer and heater.

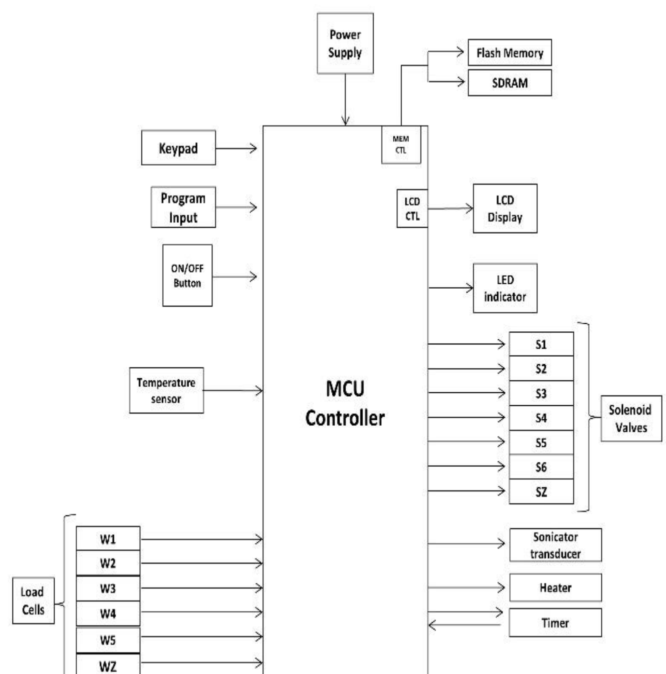

Figure 3. Block diagram of the machine controller

III. PROGRAMMING

The The programming of this machine is divided into two stages; pre-programmed information, graphical-user interface, pre-operation programming and the user mode programming.

The pre-programmed information is inserted by the manufacturer and are part of the program. These inputs cover the weights of the empty weighing containers, of nanomaterials, base fluids and dispersants, which are utilized in the machine.

The second stage occurs before operating the machine. In it, the user must manually program the machine by assigning the name of nanomaterial to its corresponding storage container. If Titanium dioxide (TiO_2) is poured by the user into container number 1, then the user should name the container "TiO_2". Assigning the container by name is also useful to program the machine with the material properties such as density of Titanium dioxide, which is 4.23 g/cm³. This input is critical for the machine to calculate the needed weight of TiO_2 in accordance with the volume fraction (%) which is set by the user. The same should be done for base fluids - for instance if water is poured into container number two, then this container should be named "Water" and its density should also be inserted, which is 0.997 g/cm3.

The last stage is not precisely programming, but rather making instructions for the desired nanofluid. In this stage the user must select the nanomaterial, base fluid, surfactant quantity, volume fraction (%), temperature and period of mixing. For the second and third stages to work, the graphical LCD is used to communicate with the user. The LCD will display the user interface which will prompt the user to insert the necessary instructions to complete the process of mixing.

IV. METHODOLOGY

The steps and processes carried out by the MCU-controller are illustrated in figure 4. The flowchart shows the maximum number of containers to operate simultaneously, which is four. Two containers for nanomaterial, one for base fluid and one for dispersant. The load cells serve to monitor the quantity needed as set by the user and calculated by the machine. The LCD screen will prompt the user to enter all desired values to initiate the process. Once the process of mixing is completed, the MCU-controller will signal the rinse water container valve to open and fill up the mixer container. After some time-delay, the valve of drain container will open. Once the drain container is filled the MCU-controller will signal the rinse water container valve to close. After rinsing of the mixer container is done, the LCD will display the end of the process and the user can start a new mixing process.

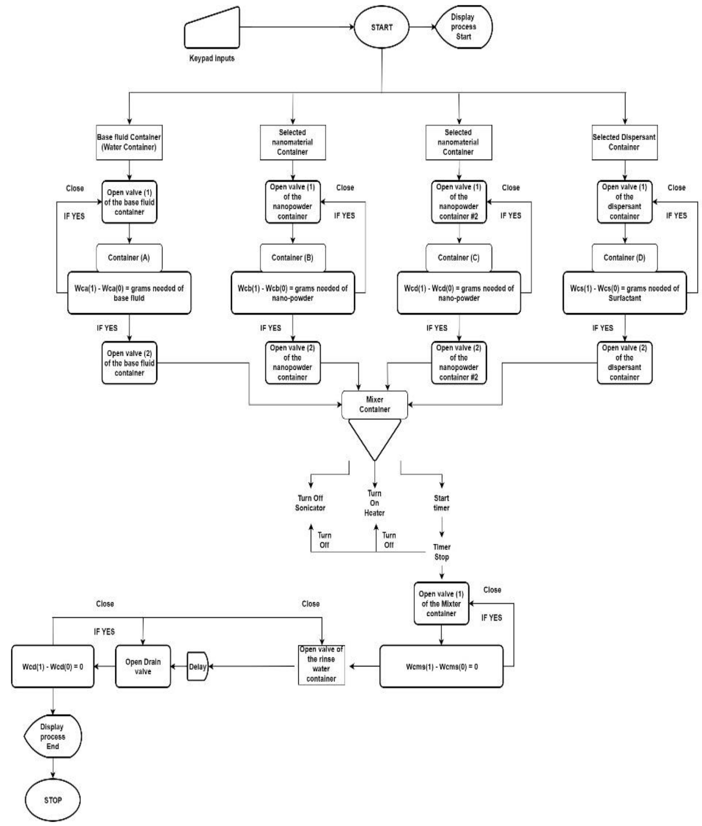

Figure 4. The MCU-Controller program flowchart

Figure 4 offers a description of the MCU-controller program which is essential for the nanofluid vending machine. The nanofluid production process is initiated with keypad input and once it is initiated, the user is notified through the LCD display. The MCU-controller will calculate the exact quantities needed of each selected material by measuring their weights in the weighing containers. Once the quantity of material is reached, the MCU-controller will signal the solenoid valves to open and the material will be poured into the mixer container. Heat and sonication will be applied to the mix for a set period. Once the period ends, the heater and probe sonicator will be turned off, while the mixer container valve will be signaled to open. The nanofluid will be poured onto a nanofluid sample container. The rinsing process occurs immediately afterwards. Water is poured from its rinse water container into the mixer container and after a set period the water will be drained into drain container. If the drain container is filled, then rinse water container valve is signaled to close. Finally, an illustration of the user interface is provided in figure 5, which shows how the LCD will ease the process of programming and setting of desired nanofluids.

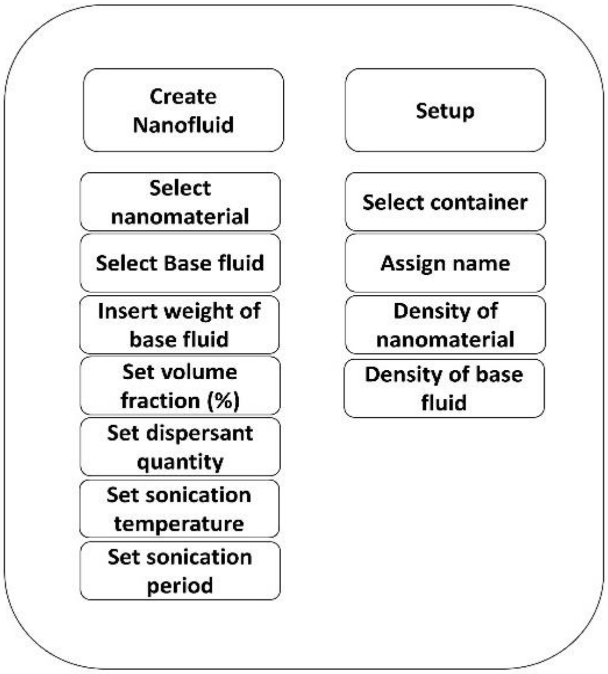

Figure 5. LCD screen user interface

The user will select either to pre-program the machine by choosing setup or instruct the machine to produce a nanofluid. The setup option is where the user will assign or label the containers based on nanomaterial poured within and add corresponding density values. If the user chooses to create a nanofluid, then the user must select the number corresponding to the nanomaterial to be used. Moreover, select the base fluid and then type in its weight. The user must also type in the volume fraction (%) desired, quantity of dispersant, sonication temperature and period.

V. Conclusion

This paper provides a novel approach to deal with and improve the process of creating nanofluids by automation. The nanofluid vending machine offers to create nanofluids at desired volume fractions, sonication temperature and time, as required by the user. Other features of this solution are to provide auto-rinsing of the mixer container which may contains leftover nanofluids. The main difference between the proposed solution and a typical vending machine is that it is fit to the purpose of producing nanofluids. The use of load cells and calculation of appropriate nanomaterial quantity to be dispersed into the base fluid. This article shows the novel approach to producing nanofluids in its beginning stage, future adjustments and improvements to be made are recommended below:

1. Add a direct method to rinse the mixer container without need for a rinse storage container. In doing so, the need for physical space of an extra container is eliminated and the process is simplified.

2. Add other mixing mechanisms and pH adjustment techniques. This will ensure higher stability of the produced nanofluids.

3. Create a large-scale configuration of the vending machine for research centers and laboratories; given that the two-step method is cost-effective for large scale production of nanofluids.

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