CHAPTER-1

INTRODUCTION
# CHAPTER – 1

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CHAPTER 1

INTRODUCTION

During the past five decades rapid advances in engineering and technology related to nuclear energy, fossil energy, electric power generation, refrigeration, heat exchangers, ink-jet printers, and electronic chip cooling have expedited research in a variety of subjects related to heat transfer. Enhancements in boiling heat transfer processes are very important, and could make these industrial applications, previously listed more energy efficient. The intensification of heat transfer processes and the reduction of energy losses have an important role to play to deal with the energy crisis. In this regard, the heat transfer boiling has been used broadly to acquire good heat transfer performance. In terms of boiling regimes, nucleate boiling is a capable heat transfer mechanism on the other hand, for the incorporation of nucleate boiling in most practical applications. For decades, researchers have been trying to develop more efficient heat transfer fluids. This would, in turn, improve process efficiency and reduce operational costs. This is where nanofluids could play a key role, nanofluids could potentially revolutionize heat transfer.

Accordingly, various techniques for improvement of the boiling heat transfer have been proposed and studied. Typical approaches that have been considered to improve pool boiling heat transfer in particular include oxidation or selective fouling of a heater surface to increase the wettability of the liquid, use of vibration of heaters to
promote the departure of bubbles from a heater surface and extended heater surface to increase the heat transfer area. An attractive advantage of using nanofluids for heat transfer applications is the capability to alter their properties such as thermal conductivity and surface wettability, for instance, can be adjusted by varying the nanoparticle concentration in the base fluid, and therefore allowing nanofluids to be used for a multiplicity of different applications. However, it is also important to note that addition of nanoparticles to a base fluid also changes the viscosity, density and even the effective specific heat these properties are also have a direct effect on the heat transfer.

Many researchers have their results showed an increase of viscosity with increased particle concentrations. There is a strong possibility that nanofluids may be non-Newtonian, even viscoelastic in some cases. Further experimental studies are needed to define the viscosity models of nanofluids.

The viscosity of Carbon nanotubes-water nanofluids as a function of shear rate was calculated by Ding et al. (2005). They observed that the viscosity of nanofluids increased by increasing Carbon nano tubes concentration and decrease in temperature. Moreover, the shear tapering behavior was found by the authors that means the nanofluids can supply better fluid flow performance due to the higher shear rate at the wall, which results in low viscosity there.
Latest advances in nanotechnology have allowed development of a new category of liquids termed nanofluids, which was first used with a group in Argonne National Laboratory USA (1995) to describe liquid suspensions containing nanoparticles with thermal conductivities, orders of magnitudes higher than the base liquids, and with sizes appreciably smaller than 100 nm. The augment of thermal conductivity could provide a basis for an enormous innovation for heat transfer intensification, which is relevant to a number of industrial sectors include transportation, power generation, micro-manufacturing, chemical and metallurgical industries, as well as heating, cooling, ventilation, and air-conditioning industry.

Among the modern technology available it is quite possible to generate ultra fine nano sized metallic and non-metallic particles which will revolutionize heat transfer enhancement methods Zeinali et al. (2007). Considering very small particle size and their small volume fraction problems such as clogging and increased pressure drop become insignificant if these particles are used along with base fluids. The relative large surface area of nanoparticles increases the stability and reduces the sedimentation in addition to dramatic improvement in heat transfer efficiency. This is possible due to reduced particle size in a suspension and increased surface area of the particles.

In this regard improving the thermal properties of energy transmission fluids may become an effective means of augmenting heat transfer. Conventional heat transfer fluids such as water,
ethylene glycol and oil have naturally low thermal conductivity relative to metals and even metal oxides. Consequently fluids with these suspended solid particles are able to offer better heat transfer properties compared to conventional heat transfer fluids.

1.1 Introduction to Boiling Heat Transfer

Boiling is the process of change of liquid into vapour at a constant temperature known as saturation temperature. When a liquid is in contact with a surface maintained at a temperature above the saturation temperature of the liquid, boiling will occur at that liquid-solid interface. Based on the relative bulk motion of the body of a liquid to the heating surface, boiling is divided into pool boiling and convective boiling.
Fig 1.1 Pool Boiling Curve  [65]
The boiling curve into six regions based on the observable patterns of vapor production.

Region I: In this region $\Delta T$ is so small that the vapor is produced by the evaporation of the liquid into gas nuclei on the exposed surface of the liquid.

Region II: In this region $\Delta T$ becomes large enough so that additional small bubbles are produced along the heating surface but later condense in the region above the superheated liquid.
Region III: In this region $\Delta T$ is sufficient enough to sustain “nucleate boiling” with the generation of the bubbles which depart and rise through the liquid regardless of the rate of condensation.

Region IV: In this region an unstable film of vapor forms over the heating surface and oscillates due to the variable presence of the film. Here the heat transfer rate decreases due to the increased presence of the vapor film.

Region V: In this region the film becomes more stable and the heat transfer rate reaches a minimum point.

Region VI: In this region $\Delta T$ is very large and “film boiling” is stable. The radiation through the film becomes significant and thus increases the heat transfer rate with increasing $\Delta T$.

This behavior as described above occurred when the temperature of the wire was the controlled (65) parameter. The wire itself comes in two grades. Extension grade and thermocouple grade. Typically the extension grade is not as precisely controlled for material content, and as a result is less expensive. The thermocouple grade is more precisely controlled, and is suited for welding thermocouples. Wire size varies greatly, but most extension grade. $\Delta T = T_s - T_i$. If the power is the controlled variable then the increase in the heat flux in Region III results in a jump in the wire surface temperature to a point in Region VI as shown figure. This point of transition is known as the critical heat flux and occurs due to hydrodynamic fluid instabilities. This
results in the stable vapour film being formed and the wire surface temperature increases as the heat transfer resistance increases for a fixed power input. But the power is now decreased the vapor film remains stable in Region VI and ΔT decreases to the minimum point for film boiling within Region V. At this point the vapor film becomes unstable and it collapse by nucleate boiling becoming the mode of energy transfer. Thus the transition through region IV and III to a lower wire surface temperature is very swift. This hysteresis behavior is always seen when power or heat flux is the controlled factor.

1.2 Boiling Phenomenon

When a liquid in contact with a surface is maintained at a temperature above the saturation temperature of the liquid, boiling will occur at the liquid-solid interface. The boiling transfer phenomenon can occur in the following forms.

1.2.1 Pool boiling

In pool boiling the liquid above the warm surface is basically stagnant and its motion near the surface is due to free convection and mixing induced by bubble expansion and later detachment from the surface.

Pool boiling is the process in which the heating surface is submerged in a large body of stagnant liquid. The relative motion of the vapour produced and the liquid surrounding the heating surface
is due to the buoyancy effect of the vapor. However, the body of the liquid as a whole is basically at rest.

**1.2.2 Forced convective boiling**

In forced convection boiling, the fluid motion is induced by exterior means in addition to free convection and bubble induced mixing. The fluid is pumped and forced to flow.

**1.2.3 Sub cooled boiling**

In sub cooled boiling, the fluid temperature is below the saturation temperature of the surface and the bubbles are produced in the surrounding area of the surface. These bubbles after travelling a short path collapse in the liquid maintained at a temperature below the saturation temperature.

**1.2.4 Saturated boiling**

In this case Saturated boiling the fluid temperature exceeds the saturation temperature the vapor bubbles produced at the solid surface (solid-liquid interface) are propelled through the fluid by buoyancy effects and finally escape from the liquid-vapor interface.

**1.3 Boiling Regimes**

The study of the pool boiling process can be traced back to as early as eighteenth century when the observation of the vapour film in the boiling of liquid over the heating surface was made by Leiden in 1756, the wide study on the effect of the very great difference in the
temperature of the heating surface and the liquid, $\Delta T$ i.e. excess temperature was first done by Nukiyama [1934]. However the experiment by Farber and Scorah [1948] gave the whole picture of the heat transfer rate in the boiling process as a function of $\Delta T$ (excess temperature). Applying the Newton’s law of cooling $q = h \Delta T$, the heat transfer coefficient $h$ was used to set apart the pool boiling process over a range of $\Delta T$ by Farber and Scorah as illustrated by the boiling curve in figure 1.1(65).

### 1.4 Research motivation

Many important industrial applications rely on nucleate boiling, to remove high heat fluxes from a heated surface and these include cooling of high power electronic tools, nuclear reactors, chemical reactors and refrigeration systems, to mention a few. Nucleate pool boiling is a very effective heat transfer mechanism. But it is well known that there exists a critical value of the heat flux at which nucleate boiling transition it is very important to maintain the operating heat flux below such critical value, which is called the critical heat flux.

Modern technology demands power and in an ever decreasing package size. As functions are increased and devices shrink, heat density increases. Fluids are essential for heat transfer in many engineering equipments. Low thermal conductivity of conventional heat transfer fluids such as water, oil, and ethylene glycol mixture is a serious limitation in improving the performance and compactness of
these engineering equipments. To overcome this drawback, there is strong inspiration to develop superior heat transfer fluids with considerably higher thermal conductivity.

The Addition of solid nanoparticles to general fluids such as water and refrigerants is an effective way to increase the critical heat flux. The resultant colloidal suspensions are known nanofluids. Popularly conceived as the next generation fluid that may modernize heat transfer, nanofluid was first created by Choi (1995) [2]. By adding tiny particles to a conventional fluid up to 40% of the fluid’s capability to transfer heat can be improved in the most of the cases. The nanofluid, which is produced by dispersing nano particles into base fluid like water and ethylene glycol, is known to significantly enhance the poor thermal conductivity of base fluids. The original concept of nanofluid is that suspensions that contain solid particles have effective thermal conductivity, however all of the studies using the concept have been faced with severe problems including sedimentation, abrasion and clogging due to the large size of the particles. The nanoparticles used in nanofluids commonly have a small average size below 100 nm in diameter. Therefore nanofluid technology has succeeded in the enhancement of thermal conductivity without the aforementioned problems. Materials used for nanoparticles include chemically stable metals such as Gold, Silver and Copper. Metal oxides such as silica, alumina, Zirconia, Titania and carbon in various forms such as Diamond, Graphite, Carbon
nanotubes. Nanoparticles are relatively close in size to the molecules of the base fluid and thus if properly prepared can understand very stable suspensions with little erosion and gravitational deposition over long periods of time. Because such nanofluids provide themselves well to real world applications different to the milli and micro size particle slurries explored in the past which rapidly settle and frequently clog the flow channels.

A few of the main factors which could enhance heat transfer are as follows i) the nanoparticles increased surface area ii) increased interaction and collisions among the particles and fluid and iii) increased mixing fluctuation and turbulence of the fluid. Owing to these attributes it is expected that the heat transfer performance of water the most widely used coolant can be improved using nanoparticles.

The research inspiration comes from the fact that nanofluid instead of conventional fluid in nature may be very effective for addressing the different types of high heat density problems. The fluid evaporation has long been recognized to have the potential for removing large amounts of heat at low temperature difference.

Given the many applications of high heat flux technology as mentioned above there is always a desire to increase the thermal performance of existing technologies. This thesis explores potential of nanofluids to enhance the heat transfer in pool boiling over the traditional fluids like water.
1.5 Research Objective

This thesis is dealt with the use of nanofluids in augmenting the heat transfer capabilities of systems. The primary objectives of this research work were as follows.

- To study the pool boiling phenomenon using a vertical cylindrical test surface immersed in different concentrations of silica and tungsten oxide nanofluid at atmospheric pressure.

- To investigate the heat transfer coefficient using a copper vertical cylindrical test surface immersed in different concentrations of silica and tungsten oxide nanofluid at atmospheric pressure.

- To investigate the heat transfer coefficient using a brass vertical cylindrical test surface immersed in different concentrations of silica and tungsten oxide nanofluid at atmospheric pressure.

- To investigate the heat transfer coefficient using a stainless steel vertical cylindrical test surface immersed in different concentrations of silica and tungsten oxide nanofluid at atmospheric pressure.

- To investigate the reasons for increase or decrease in heat transfer coefficient by subjecting the test surface to different concentrations of nanofluids.

- Nanofluid was prepared in different concentrations using two step method dispersing silica and tungsten oxide nanoparticles in pure water. The dispersion was then excited in vibrating machine.
• Heat transfer coefficient enhancement was studied using an experimental setup mounted with 12mm diameter of copper, brass, stainless steel in vertical position.

1.6. **Merits of Nanofluids**

Once the particles are properly spread the characteristics of nanofluids are possible to be useful.

1.6.1 **Process of heat conduction**

Due to the great surface area of nanoparticles allow for additional heat transfer. Another advantage is the mobility of the nanoparticles, compatible to the tiny size, which may help in regarding micro-convection of fluid and hence enhance heat transfer. The micro-convection and improved heat transfer may also raise diffusion of heat in the fluid at a faster rate.

1.6.2 **Stability in nature**

Because the particles are under sized, they weigh less and the probability of sedimentation is also low. This abridged sedimentation can to overcome one of the main drawback of suspensions the settling of nanoparticles is making the nanofluids more stable in nature.

1.6.3 **Decrement in chances of corrosion**

Nanoparticles are exceptionally small and the thrust they container convey upon a solid wall is greatly smaller. This condensed
momentum decrease the possibility of erosion of machinery such the same as heat exchangers, pumps and pipelines.

1.6.4 Micro control cooling

Nanofluids will not simply be a greater medium for heat transfer in general but they will also be final for micro control functions wherever high heat load are useful. The variation of micro channel and nanofluids will pass on both really conducting fluids and an vast heat transfer area. This cannot be gain with micro particle since they clog up micro channel.

1.6.5 Decrement in pump control

To enhance the heat transfer of conventional base fluid by a factor of two, pumping power must generally be amplified. In the holder of nanofluids the thermal conductivity is sharp compared to conventional base fluids. So heat transfer coefficient improve better without any extra pumping power. Thus, very huge reserves in pumping power can be achieved if a large thermal conductivity enhancement is brought about with a small volume fraction of particles.

Additional research is needed to develop the appropriateness of employ in heat transfer applications, the convective heat transfer with conventional fluids itself is reasonably complex and forecast of heat transfer is to be adequately establish. The explanation of heat transfer
is based on exhaustive experimental study that resulted in empirical relations mostly based on non-dimensional analysis the heat transfer behavior of nanofluids is very complex and the application of nanofluids for heat transfer enhancement cannot be decided only by their effective thermal conductivity. Many other factors such as particle size, shape and distribution, micro-convection, pH value and their particle fluid interactions may have important influence on the heat transfer performance of the nanofluids in natural and forced convective heat transfer, considering the limited experimental studies available on the natural and forced convective heat transfer in nanofluids.