1
Introduction

1.1 BACKGROUND AND INTRODUCTION

The concept of potable water is prominent in arid environments, for example in the regions of the Thar desert, India. Here, the populace lives in villages which possess poor infrastructure and sanitation facilities [Montgomery and Elimelech , 2007; Gadgil, 1998]. Access to safe drinking water is regional and point of use level issue which requires a technological intervention.

The recent developments and population growth have observed marriage between the phenomenon of the physical and economic scarcity of water [Plappally and Lienhard, 2013]. The scarcity of technological provisions or impossibility of the reach of technology to a location can also cause water scarcity. This phenomenon can be treated as technological scarcity for water at a given location of the earth. Locations on the Earth such as vast deserts (an example is the Sahara with salty water oasis), mountains, the islands within the sea etc can be probable places with no technology access and hence deprived of good quality water [BBC Earth, 2016].

The safe and clean drinking water remains out of reach from over 884 million people around the globe [Pindi *et al*., 2013 ; Rosinger, 2018]. These people are left with no choice but to drink contaminated water. Drinking insufficient amount of water can cause malnutrition, arrested growth and development, dehydration and death [Checkley *et al*., 2004; Kosek *et al*., 2003; Lantagne, 2001c; Sobsey *et al*., 2008; Wenhold and Faber, 2009]. The human body uses water to regulate its temperature and other bodily functions. It also carries nutrients, nourishes cells and then it removes wastes from cells. It is also essential for hydration and food production [DRI, 2004; Haussinger *et al*., 1994]. Indirectly or directly, water affects all the facets of human life. An inappropriate nexus is spewing between drinking water and human health culminating into financial expenses [Plappally *et al*., 2010, HBPH].

The physical, technological and economic water scarcity have been the three factors which have significantly contributed to the ongoing safe and adequate drinking water demands in rural India [Gupta *et al*., 2015, Plappally *et al*., 2013, HCR]. Government, communities and civil societies have shown commitment to bring basic technological intervention of supplying water to 700 million people of rural India through flagship schemes (such as Clean India Mission), piped water supply, household tap connections, public standpipes and boreholes. However, the cases of contaminated water at the point of use due to the hand pump and pipeline corrosion and the leaching of chemicals into the water makes these methods of water supply less sustainable and reliable [Rao, 2004].

Looking at the various factors for health burden in developing countries documented by WHO, unsafe water, poor hygiene and sanitation marks third position. Over 28 billion diseases were reported to occur due to ten major water borne diseases [WHO, 2003]. Diarrheal diseases are reported to be the big killers especially to the infants [WHO/UNICEF, 2008]. The microbial contamination in drinking water is a health hazard in the developing world [Plappally *et al*., 2010, HBPH]. As per WHO, three million children below the age of five die annually due to diarrheal disease [WHO, 2003]. The vast majority of the diarrhoeal disease (88%) case occurrences in rural areas of India has been attributed to the physical scarcity of water, ill-maintained sewer lines, unsafe disposal of solid wastes, unawareness of sanitation and hygienic practices [WHO, 2003; Kindhauser, 2003; UNICEF, 2008].

Apart from biological contamination, the presence of toxic chemicals (such as arsenic, fluoride, nitrate, lead etc) in sources of water can be dangerous to health [Pradeep and Anshup, 2009]. Arsenic and fluoride have been considered the most significant chemical contaminants of drinking water at the global scale [Fawell, 2006;WHO, 2000]. Arsenic enters the water stream through natural and industrial sources [Mohan and Pittman, 2007]. Subsurface and groundwater with high arsenic concentration can be found in many parts of the world. The prolonged exposure to water containing arsenic concentration greater than 10 ppb can cause cancer of skin, lungs, bladder and kidney. It can also lead to lichenification and skin pigmentation disorders [Smith and Smith, 2004]

The literature discusses various methods, devices, techniques to tackle water treatment issues around the globe. The point of use treatment technology involves purifying water at the household level. Out of several POU techniques MIT Kanchan Filter and clay based porous ceramic water filters (CWF) proved to provide sustainable water solutions [Clasen and Boisson, 2006; Lantagne *et al*., 2010; Lantagne, 2001a,2001b,2001c; PFP; Sobsey *et al*., 2008].

Studies on locally and commercially produced CWF has been performed at different locations of the world to test their potential for removing microbial contamination in water [Plappally and Leinhard, 2013]. Few fundamental engineering studies on properties of CWF can also be found. The effect of surface characteristics on the strength of the ceramics needs detailed exploration. Moreover, the local CWF (G Filter) design needs modification for specific contaminant removal and for sizing or scale up to enhance water productivity [Gupta *et al*., 2018]. It is not highly effective at removing heavy metal contaminants. The problems can be resolved by exploiting clays' adsorption properties. CWF is also of a fragile nature, which results in their breakage during fabrication, operation period and movement from one place to another and [Plappally *et al*., 2012]. Therefore it's required to modify the composition of porous clay ceramics.

Rajasthan, an Indian state is well known for its marble production, iron and steel metal manufacturing and timber based handicraft industries [Pappu *et al*., 2007; Giyar, 2011]. The tons of wastes generated from these industries are issues of concern. Marbles or limestone contain a large fraction of CaO (quicklime or burnt lime) which forms the basis of Clark's process used to soften water. Quicklime, when appended with water, forms calcium hydroxide (slaked lime) and has been used to precipitate hardness [Freese *et al*., 2003].

The mixing of slaked lime with polluted water is performed to raise the pH to above 10.5 to 11.5. This alkalinity initiates flocculation. Re-carbonation of that water with CO2 bring the pH value to 8 precipitating Ca present (including the CaHCO3 if present in the water) as the carbonate, thereby forming a floc. This process, therefore, softens water and removes heavy metals and organic suspended matter originally present in the contaminated water. Therefore locally available marble waste becomes a sustainable working choice in manufacturing the G Filter.

It is said that Fe and As are two major contaminants in rural water sources in India [Loksabha, 2017]. But Fe in different forms (example zero valent iron or iron filings) or when combined with other minerals may also form a water treatment material [Plappally, 2010; Plappally and Lienhard, 2013]. $FeCl_3$, $FeSo_4$ and alum are used as coagulants [Aziz *et al*., 2007].

This dissertation proposes a low cost, waste material embedded clay-based ceramics through the incorporation of such locally available industrial wastes of Fe machining and marble processing or mining. This proposal can also be viewed as a solid waste management strategy. The correlations discussed between surface roughness characteristics, porosity and mechanical strength of these clay filtration systems add to the so far fundamental scientific knowledge of porous ceramic water filters.

The experimental studies are performed to showcase enhanced arsenic (V) adsorption capacity through mixed additive in novel sintered clay materials developed. Moreover, the high efficiency of microbial removal by these ceramic composites underscores its potential as means of low cost water purification ceramic device.

1.2 RESEARCH OBJECTIVES

The thesis presents empirical and theoretical investigation that paves the way for the development of a set of low-cost water filtration techniques which are based on local raw material specific to Western Rajasthan. They are clay, marble slurry and Fe fines. The thesis aims to develop a valuable product from materials that are either waste or easily available and affordable. The objectives of the current work -

- To understand the correlation between the surface roughness of porous ceramics with porosity and mechanical strength.
- To develop an understanding of the effect of the addition of industrial wastes on the composition, morphology, strength of clay ceramics.
- To demonstrate the role of industrial wastes in improving arsenic removal efficiency of clay ceramics.
- To study the effect of altering filter composition in the sustenance of microbial removal capabilities.
- To provide a new set of low-cost ceramics which have the potential for scale-up in household water treatment systems, wetland reclamation and wetland based water treatment.

1.3 SCOPE AND ORGANIZATION OF THESIS

With the background and motivation described in this section, the relevant detailed literature is reviewed in **chapter 2**. **Chapter 3** then elaborates on the instruments used to quantitatively and qualitatively characterize the ceramic specimens.

Chapter 4 is used to evaluate the effect of physical properties like porosity and surface roughness on the structural strength of ceramics. The role of sawdust on the fracture toughness behavior was explained using linear transform equation. A theoretical model, based on Darcy's equation is used to determine the discharge and percolation through distinct geometries.

Chapter 5 discusses the effect of the addition of ferrous mill waste on the mineralogy, microstructure, physical properties and mechanical sustenance of ceramic membranes was discussed. The chapter also discusses the arsenic (V) adsorption studies on the modified ceramics.

Chapter 6 presents the results of the addition of marble slurry on the composition, microstructural evolution, and mechanical behavior of marble based ceramic membranes. The chapter elaborates on As (V) adsorption studies. The prominent results inferred from this work are summarized in **Chapter 7**, along with suggestions for future work.