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Feasibility study of "green" insulation materials including tall oil: Environmental, economical and thermal properties

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ABSTRACT

In the present work, insulation materials are produced by using clay (C), fly ash (FA), rice husk ash (RHA) and epoxidized tall oil (ETO). Density and thermal conductivity properties of these materials are analyzed. Environmental and economical analyses of sample with code T36 as insulation material are numerically investigated by using a computer program developed in LINGO. The optimum insulation thickness of this insulation material applied externally on wall for Elazığ city of Turkey, energy saving over a lifetime of 10 years, payback periods, sensitivity analysis and emissions of CO_2–SO_2 versus insulation thickness are calculated for the four energy types.

1. Introduction

One of the most common issues for Turkey and other countries is saving on the energy and the used raw materials in the production of building materials such as insulation material. Especially, energy savings have great importance in Turkey which can be considered as self-sufficient as regards of the industrial raw material sources. Hence weight should be given on to the production of light weight building materials with low thermal insulation value. In this regard, many studies and research have been conducted recently about the use of waste-renewable-natural products in the production of building material in consideration of environmental concerns and in order to save on raw materials for building material making.

The last few years show an increased interest in work involving the preparation and study of surfactants based on natural products. Plant oils which are obtained from plant sources are quite abundant in nature. Plant oils containing epoxy groups are important oleo chemicals [1]. Triglycerides are the main component of plant oils. Among the triglyceride oils, linseed, sunflower, castor, soybean, oiticica, palm, tall and rapseed oils are commonly used for synthesis of oil-modified polymers. Triglyceride-based resins are an attractive alternative to petroleum-based resins because they are inexpensive, universally available, have good properties, and are derived from renewable resources [2,3]. In addition epoxidized plant oils can be used as reactive diluents for paints and as intermediates for polyurethane–polyol production [1]. Triglyceride-based polymers have been used as toughening agents in polyvinyl chloride (PVC) and epoxy resins [4], and as the major component of a number of natural resins [5,6], composites (polyurethane, polyester, polyether, etc.) [5,7,8], and pressure-sensitive adhesives [5,9]. Rapeseed, sunflower, soybean and linseed oil, etc. can be epoxidized with selectivity and conversions well above 90% [5,8]. Recently, epoxies have received increased attention because they are of interest both as end-products and as chemical intermediates; epoxidized oils and their ester derivatives have thus found important applications as plasticizers and additives for PVC [10]. Tall oil is a typical oil since it is not obtained from oil-bearing seeds or fruits like other vegetable oils. Tall oil is a by-product of the paper industry, where it is recovered from the 'black liquor' resulting from the Kraft (sulfate) pulping of coniferous woods. The obtained dark-colored crude tall oil is not composed of pure triglycerides, like other vegetable oils, but is rather a mixture of fatty acids, rosin acids and unsaponifiable matter (e.g., sterols, waxes, hydrocarbons) in a ratio of 5:4:1. The fatty acid fraction can be enriched by fractional distillation to a product that is known as tall oil fatty acids, which contains mainly oleic and linoleic acid. It is chiefly used for the production of alkyd resins and dimer acids [11]. Tall oil has attracted special attention. Tall oil, with its low cost, and as a large quantity

Abbreviations: C, clay; FA, fly ash; RHA, rice husk ash; ETO, epoxidized tall oil; TO, tall oil.

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Nomenclature

K	constant of Shoterm QTM Apparatus
H	constant of Shoterm QTM Apparatus
$t1$	temperature of startup (K)
$t2$	temperature of finish (K)
V_1	the startup voltages of thermoelement (mV)
V_2	the finish voltages of thermoelement (mV)
k	thermal conductivity coefficient [W/(m K)]
T_{avr}	average temperature (K)
C_A	annual energy cost [TL/(m^2 yr)]
C_i	cost of insulation in (TL/m^3)
C_{ins}	cost of insulation in (TL/m^2)
C_f	cost of the fuel ($/kg)
D	inflation rate
DD	degree days (°C days)
EA	annual heating load [J/(m^2 yr)]
Hu	heating value of the fuel (J/kg)
I	interest rate
m_f	fuel consumption per year (kg/yr)
M	molecular weight of fuel
Ms	ratio of the annual maintenance and operation cost to the original first cost
N	lifetime (yr)
N_p	payback period (yr)
R_i	inside air-film thermal resistances [(m^2 K)/W)]
R_{ins}	thermal resistance of the insulation layer [(m^2 K)/W)]
R_o	outside air-film thermal resistances [(m^2 K)/W)]
R_w	total thermal resistance of the wall materials without the insulation [(m^2 K)/W)]
R_{wt}	sum of R_i, R_w, and R_o [(m^2 K)/W)])
R_v	ratio of the resale value to the first cost (TL)
S	energy cost savings (TL/m^2)
T_b	base temperature (°C)
To	mean daily temperature (°C)
U	overall heat transfer coefficient [W)/(m^2 K)]
q_A	annual heat loss in unit area (W/m^2)
X	thickness of the insulation material (m)
h_s	efficiency of the heating system

by-product of forest and pulp industry, has been used mainly in protective coatings, soaps and ore floatation [12,13]. Many researchers have reported their studies on the conversion of tall oil fatty acid to fatty acid methyl ester products [14–16]. Since tall oil fatty acid also has unsaturation, it can be considered as a possible option for the starting material of biobased thermoset [17]. Tall oil is widely used in industrial applications, such as in nylon, glue, and iron-steel industries, and is also used as an additive in the production of diesel fuel. However, because of the high rate of the development of the polymer industry, especially ureaurethane elastomers, tall oil is now used in this industry [18]. TO industry and TO production in the world are given in Figs. 1 and 2, respectively [19,20].

A lot of research is currently being done into recycling, into how to reuse the waste we produce in our daily lives. The building industry has always shown a receptive attitude to research into new materials [21]. FA, a by-product of coal combustion, is frequently used in concrete production as an inexpensive substitute for Portland cement. FA has low unit weight, low compressibility and pozzolanic reactivity [22]. Its pozzolanic properties improve the strength of the concrete, and its small particles make the mixture easier to knead [23]. The utilization of FA is realized by low technology applications such as in construction of fills and embankments, backfills, pavement base and subbase courses, for subgrade stabilization, as landfill cover, land reclamation and flowable ash slurry; medium technology applications such as in production of blended cement, concrete pipes, precast/prestressed products, in construction of roller compacted concrete in dams, autoclaved cellular concrete, in production of bricks, blocks and paving stones and lightweight aggregates to be used in geotechnical applications as well as concrete production; high technology applications such as material recovery, fillers for polymer matrix composites and metal matrix composites and other filler applications. Turkey produces more than 15 million tons of FA annually but only a small amount is utilized. The amount utilized is realized by blended cement production, some local facility constructions and in place of natural sand for the manufacture of building materials [24–26].

Rice husk is one of the most widely available agricultural wastes in many rice producing countries around the world. Globally, approximately 600 million tons of rice paddies are produced each year. On average 20% of the rice paddy is husk, giving an annual total production of 120 million tones [27]. Rice husk has been widely used as fuel in the rice paddy milling process. The use of this fuel generates a large volume of rice husk ash (RHA) usually discarded into landfills, and causing pollution and contamination to water resources. To preserve the environment, the interest in using rice husk ash (RHA) in construction industry has increased tremendously [28–31]. By burning rice husk at controlled burning temperatures below 700 °C, amorphous silica in RHA is formed which is highly reactive [32,33]. The analyses showed that the highest amounts of amorphous silica occur in rice husk burnt in the range of 500–700 °C [34]. For RHA processed with higher burning temperature with some crystalline silica, reactive RHA could be obtained by fine grinding [35–37]. The properly burnt and ground rice husk can be used as a mineral admixture in cement production [38,39], and the behavior of cementitious products varies with the source of RHA. High amounts (up to 30%) of RHA could be blended with cement without adversely affecting the strength and permeability of concrete [40]. RHA is a good super-pozzolan. There is a growing demand for fine amorphous silica in the production of special cement and concrete mixes with high performance, high strength, and low permeability, for use in bridges, marine environments, nuclear power plants, etc. In many studies, concrete materials are designed with a very small volume fraction of rice husks and sometimes even with sand. In these works [41–43], samples are especially studied in terms of mechanical performances. Other uses [44] of RHA is green concrete, refractory, ceramic glaze, insulator, roofing shingles, waterproofing chemicals, oil spill absorbent, specialty paints, flame retardants, carrier for pesticides, insecticides and bio-fertilizers, etc. Fig. 3 shows world production rate for rice paddy and rice husk ash [45].

C is a naturally occurring material composed primarily of fine-grained minerals [46]. It is an inexpensive natural mineral that has been used as filler for rubber and plastic for many years. It can be chemically modified to make the C complexes compatible with organic monomers and polymers [47]. Chemical and structural modification of clay material during firing generally improves mechanical strength and durability of bricks [48].

Thermal properties of building materials such as clay used in construction are reported by many researchers, in order to provide industrial designers with values based on high levels of confidence [49,50]. Zhang and coworkers prepared highly porous thermal insulation materials with coal fly ash-clay by combining foaming method and slip casting process. The compressive strength of these materials is varied from 0.43 MPa to1.01 MPa. The lowest thermal conductivity was obtained as 0.0511 W/(m K) [51]. Drochytkaa et al. investigated the thermal qualities of the produced autoclaved aerated concrete with fly ash-sand. The thermal insulating properties of autoclaved aerated fly ash-based concrete showed better properties when compared with autoclaved aerated sand concrete [52].