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INVESTIGATION OF THE USE OF NANOPARTICLES IN THERMAL INSULATION MATERIALS

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Abstract

Original scientific paper

Today, the concept of energy conservation has become a much more important concept due to the difficulty in accessing energy and the increasing cost of energy resources. The fact that fossil energy resources have started to be depleted in recent years worldwide has led mankind to renewable and sustainable energy resources. However, the fact that such resources are not yet at a level to meet the needs has shown the necessity of using energy economically. In our research, the thermal conductivities of the nanoparticles produced by us were determined in terms of evaluating the use of nanoparticle materials, which is a new perspective on energy saving, in thermal insulation materials. Then, the thermal conductivity coefficients of the nanoparticles in the literature were investigated and compared with the values of the nanoparticles produced by us, and the suitability of the use of the nanomaterials we produced in insulation materials was evaluated. In the study, the heat transfer coefficients of Al_2O_3 and CuO nanoparticles were found to be 34.2 and 65.4 W/mK, respectively. In the literature review, it was seen that these values were 36 and 65.8, respectively. As a result of the evaluations, it was observed that the CuO nanoparticle produced by us gave similar results with the literature, and the Al_2O_3 nanoparticle gave better results than similar studies at a rate of 5%.

Keywords: *Nanoparticles, thermal insulation, energy saving.*

NANOPARÇACIKLARIN ISI YALITIM MALZEMELERİNDE KULLANIMININ İNCELENMESİ

Özet

Orijinal bilimsel makale

Günümüzde enerjiye ulaşımın zorlaşması ve enerji kaynaklarının giderek pahalılaşmasından dolayı, enerji tasarrufu kavramı çok daha önemli bir kavram haline gelmiştir. Dünya genelinde son yıllarda fosil enerji kaynaklarının tükenmeye başlamış olması, insanoğlunu yenilenebilir ve sürdürülebilir enerji kaynaklarına yönlendirmiştir. Fakat bu tür kaynaklarında henüz ihtiyaca cevap verecek düzeyde olmayışı, enerjiyi tasarruflu bir şekilde kullanmanın gerekliliğini göstermiştir.
Araştırmamızda enerji tasarrufu konusunda yeni bir bakış açısı olan nanopartikül malzemelerin ısı yalıtım malzemelerinde kullanılmasının değerlendirilmesi yönünden hem tarafımızca üretilmiş olan nanopartiküllerin ısıl iletkenlikleri tespit edilmiştir. Daha sonra literatürdeki nanopartiküllerin ısı iletim katsayıları araştırılıp tarafımızca üretilmiş olan nanopartiküllerin değerleri ile karşılaştırma yapılarak, yalıtım malzemelerinde üretmiş olduğumuz nanomalzemelerin kullanımının uygunluğu değerlendirmelere tabi tutulmuştur. Çalışmada, Al_2O_3 ve CuO nanopartiküllerinin ısı transfer katsayıları sırasıyla 34.2 ve 65.4 W/mK olarak bulunmuştur. Literatür taramasında bu değerlerin sırasıyla 36 ve 65.8 olduğu görülmüştür. Değerlendirmeler sonucunda tarafımızca üretilmiş olan CuO nanopartikülünün literatürle benzer sonuçlar verdiği görülmüş olup Al_2O_3 nanopartikülünün ise %5 oranında benzer çalışmalara göre daha iyi sonuç verdiği gözlemlenmiştir.

Anahtar Kelimeler: *Nanopartikül, ısı yalıtımı, enerji tasarrufu.*

1 Introduction

With the developing technology, it has become easier for human beings to access energy resources. This has led to an increase in energy consumption and new research on the efficient use of resources. Due to the climate crisis and drought caused by global warming, the amount of energy produced from hydroelectric power plants and wind power plants has decreased significantly. This situation has led to an increase in the use of fossil fuels, one of the most traditional methods of energy production, and the inability to meet the energy demand due to the decrease in resources. There has been a significant increase in the use of renewable energy sources in Turkey. However, this increase still has a small share in the energy used. According to the reports of the Turkish Electricity

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Transmission Company (TETC), the share of wind and solar energy in total energy production is 12 percent, while the share of hydroelectric energy production in total consumption is 25.6 percent [1]. As can be understood from the published report, most of the energy production in Turkey is still provided by fossil fuels, and in case the demand cannot be met, exports are resorted to. According to a report by Anatolia Agency, in the first quarter of 2021, Turkey's energy imports increased by 9.6 percent compared to the same period last year and amounted to 61 billion dollars [2]. Another problem caused by fossil fuels is air pollution. In the report published by the Right to Clean Air Platform, it is stated that air pollution has caused more than six times more deaths than traffic accidents every year since 2017, and Istanbul has been the city with the highest number of deaths due to air pollution since 2017 [3]. For these reasons, it is important to take energy saving measures in Turkey in order to reduce deaths due to air pollution, to reduce the share of energy imports and to use resources efficiently. The simplest definition of a nanoparticle is a particle on a very small scale. The nanoscale defines the range of 1-100 nm. The basis on which nanotechnology is focused on is defined by the American National Nanotechnology Initiative as "the essence of nanotechnology is the ability to work at the molecular level, atom by atom structuring, basically creating large structures with new molecular arrangements". Nano materials are a general name given to materials used in nanotechnology. Nano materials science is the branch of science that studies how materials behave at the nano level. The high area-to-volume ratio of nano materials opens the door to new applications. This is also known as the quantum effect. This also affects biomaterial applications. With the quantum effect, the size of particles decreases and the electronic properties of materials change; various metal, semiconductor and insulator nanomaterials gain importance with this change in their mechanical, magnetic, optical and chemical properties. The physical properties of materials reduced to nano size change. Nano technology is the development of new materials, systems and devices using these unusual properties of materials. In other words, there are two important goals underlying nanotechnology. The first is to utilize the different properties of nano materials developed by using special production techniques, and the second is to change the internal structure of large-scale materials at the atomic level in a controlled manner and thus to give them extraordinary properties [4]. The main reason for heat loss in buildings is that heat wants to pass from a high-temperature environment to a low-temperature environment. According to the report of the Chamber of Mechanical Engineers, the thermal comfort condition is 50 percent relative humidity and indoor temperature ranging between 20-25 °C [5]. If the interior surface temperature is 5-6 °C different from the space temperature, a thermal bridge is formed on the building surface. Columns, beams, beams, curtain concrete and slabs that form heat bridges in buildings cause heat loss up to 20-50 percent on the outer surface of the building. The reason for such a high percentage is that the thermal conductivity of reinforced concrete has a high value of 2.1 W/mK. Another problem caused by thermal bridges is condensation. Condensation causes paint and plaster flaking, fungus and mold on the inner and outer surfaces of the wall. The reason for condensation is that the partial pressure due to temperature causes vapor transmission due to the difference between the indoor and outdoor environment. Condensation occurs due to the incompatibility between the thermal conductivity and vapor diffusion resistance values of the materials forming the wall. Thermal insulation is a system designed to minimize heat exchange between one region and another. Thus, the formation of thermal bridges and condensation can be minimized and a comfortable life can be ensured in buildings. Nanostructured materials such as nanoparticles, nanowires and nanolaminates have attracted great interest in applications in many fields due to their large specific surface areas and extraordinary physical properties. In the theoretical studies first carried out by Phaser, it was found that the thermal contact resistances between nanoparticle particles were high. For this reason, it was concluded that the thermal conductivity of nanoparticle beds may be lower than the minimum thermal conductivity in the Einstein limit. The low thermal conductivity of a material is related to its low heat conductivity. It is preferred that the thermal conductivity of thermal insulation materials is close to zero. In other words, the lower the thermal conductivity, the better the thermal insulation performance of the material [6]. These ultra-low thermal conductivities in nanoparticle beds were observed in experimental studies conducted by Hu et al. In this study, commercially available nanoparticles with nominal particle sizes of 300 and 500 nm were used. Alumina nanoparticle samples were pressed with the help of stainless steel rods. The thermal conductivity of the particle bed was measured with a heat conduction apparatus. The purpose of choosing steel rods is to increase the precision of the measurement. In the tests, the temperature of the adjacent thermocouple was measured around 1-2 °C and the precision was +-0.2 °C. The thermal conductivity of the packed alumina nanoparticle bed was measured to be 0.035W/mK. This value is only 35 percent higher than the thermal conductivity of air and smaller than the lowest thermal conductivity of tungsten diselenide (WeS_2), the most widely used thermal insulation material. This suggests that alumina nanoparticle beds would be suitable for high-temperature thermal insulation and energy conversion applications. In addition, since nanoparticle beds are insensitive to external pressure, they have low thermal conductivity even at high pressure [7]. Mishra et al. aimed to produce thermal insulation material from oxide nanoparticles. As a result of the experiments, it was concluded that oxide nanoparticles can be limited by low melting points at high temperature. As a result of using silica and alumina nanoparticle beds together, it has been observed and reported that the phase transformation of alumina will occur at a temperature lower than 1200 °C and the structure shrinkage of silica will start at a temperature lower than 1000 ˚C. The fact that phase transformation and structure shrinkage occur at such high temperatures is an important indicator that the silica and alumina nanoparticles used can be used in thermal insulation materials [8]. According to the studies conducted by Wu et al., oxide nanoparticles can be used in thermal insulation materials due to their low thermal reliability at high temperatures. Firstly, silicon carbide powders were compacted in a powder compaction machine to form a cylindrical nanoparticle bed. In the formation of the beds, different pressures such as 2,4,6,6,8,8,10,12 and 15 MPa were applied to obtain multiple different pore structures. Six of each sample were prepared to obtain an average conductive value for each pressure value. The samples were heated in a vacuum tube furnace, increasing the temperature by 10 K/min each time. Thermal conductivities at different temperatures were measured with the help of a special device. By this process, the thermal conductivity, phase transformation temperature, radiation heat transfer and convection heat transfer of the nanoparticle beds produced were found. In the light of these data, it was reported that SiC has a thermal conductivity of less than 0.07 W/mK and can be an excellent thermal insulation material. It was also observed that Silicon Carbide (SiC) retains its morphology up to 1800 C due to its thermal contact resistance at high temperatures and can resist up to 2000 °C without phase transformation [9]. In the study by Kuşkonmaz, the conditions required to produce high density Al_2O_3 at high pressure and different sintering temperatures were investigated. The starting powder used to produce the nanoparticle bed was selected as 20nm on average. The starting powder was heated at 700 °C for three hours to lose its binding properties. Then, Al_2O_3 powder without any additives was cold pressed by applying 20 mPa pressure and samples with a diameter of 20 mm and a height of 10 mm were obtained. To prevent grain growth, 10 percent of the weight of TiO_2 was added to each sample by sol-gel method. Phase analysis of the sintered samples was performed by X-ray diffraction and grain sizes were estimated from high-resolution scanning electron micrographs. Microhardness was determined on polished surfaces by applying load to the samples.

As a result of these studies,

- Effect of applied pressure duration on phase transformation,
- All sintered samples showed the presence of α phase without evidence of γ phase.
- It was also determined that under the applied pressure and temperature, the sintering time had no significant effect on the phase content [10].

These studies with alumina silica and carbon nanoparticles show that nanoparticles can be used in thermal insulation due to their high thermal resistance. One of the most important factors of heat losses is the gaps in the carrier systems. According to the Guidelines for the Imaging of Building Heat Losses with Thermal Camera published by the Ministry of Environment and Urbanization, heat losses in buildings monitored with thermal camera are shown in Figure 1. Close-up thermal imagery provides the necessary information about the structure of the walls and heat loss. As seen in Figure 1, heat losses from windows can be detected with digital systems. Necessary measures are taken in line with these determinations.

Figure1. Heat Loss through Window Openings [11].

In the study by Ning Li et al., nano antimony (flame retardant) doped tin oxide (ATO) was synthesized by sol gel method and nanoparticles were produced. The zeta potential (intergranular repulsion or attraction value), dispersant and pH values affecting the stability of the produced nanoparticles were evaluated. Antimony doped tin oxide (ATO) suspension with high stability was prepared and it was observed that pH value, dispersant type and dosage have a significant effect on the stability of ATO suspensions. For example, an ATO suspension with pH= 6-10 has a higher zeta potential and better stability. The study also indicated that among various dispersants, the stability of ATO suspension using poly acrylamide and sodium polyphosphate can be significantly improved and it is a reliable method to prepare stable suspensions of ATO nanoparticles for heat insulating glass paint [12]. Wu et al. investigated the addition of SiO_2 nanoparticles as an additive to insulation material. In addition to the addition of SiO_2 nanoparticles, they also added sawdust to the insulation material. They achieved a 15% decrease in density value with the addition of SiO_2 nanoparticles and 20% sawdust in the insulation material. They also concluded that it offers significant contributions with a 22% decrease in thermal conductivity [13]. Liu et al. investigated Silica aerogel used as insulation material in buildings. They investigated the contribution of nanoparticle additives such as SiO_2 and SiC to thermal conductivity values. They concluded that fiber-reinforced aerogel composites contribute to the thermal conductivity at high temperature [14].

Studies on thermal insulation applied to glass have revealed the necessity to find more transparent thermal insulation materials with the correct thermal insulation. Making maximum use of sunlight is at least as important for energy saving as proper thermal insulation. In their study, Ran et al. worked to further improve the transparent thermal insulation of Cs_xWO_3, which is frequently used in window glass with higher visible transmittance, near-infrared capability and energy saving due to its thermal stability. A controllable synthesis of Cs_xWO_3 nanoparticles was realized by solvothermal method from $Na_2WO_3.2H_2O$ and Cs_2SO_4, which are inexpensive and environmentally friendly. The reducibility and reduction mechanisms of citric acid, tartaric acid and oxalic acid were investigated. It was confirmed that tartaric acid has the strongest reducibility and can produce the most W5+ and oxygen vacancies in the production of Cs_xWO_3 before heat treatment.

After heat treatment, Cs_xWO_3 nanoparticles exhibited the best crystallinity and the visible light transmission was found to be about 10 percent higher than tartaric acid and citric acid [15]. In our research, the thermal conductivities of the nanoparticles produced by us were determined in terms of evaluating the use of nanoparticle materials, which is a new perspective on energy saving, in thermal insulation materials. Then, the thermal conductivity coefficients of the nanoparticles in the literature were investigated and compared with the values of the nanoparticles produced by us, and the suitability of the use of the nanomaterials we produced in insulation materials was evaluated. In the study, the heat transfer coefficients of Al_2O_3 and CuO nanoparticles were found to be 34.2 and 65.4 W/mK, respectively. In the literature review, it was seen that these values were 36 and 65.8, respectively. As a result of the evaluations, it was observed that the CuO nanoparticle produced by us gave similar results with the literature, and the Al_2O_3 nanoparticle gave better results than similar studies at a rate of 5%.

2 Materials and Methods

2.1 Materials and Tools Used in Nano Particle Production

2.1.1 Materials Used in Particle Production

Aluminum Acetate, Copper Acetate, Sodium hydroxide, Ammonia, Pure Water were used in the content of nanoparticles produced by us under laboratory conditions.

2.1.2 Electronic Precision Weighing

The electronic precision balance used to adjust the material quantities is given in Figure 2.

Figure 2. Electronic precision scale.

2.1.3 Electronic Fish Mixer

The electronic fish mixer with speed and temperature settings is shown in Figure 3.

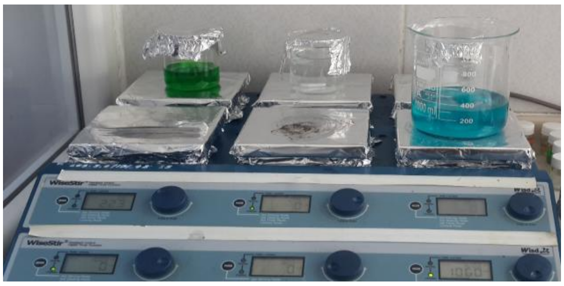

Figure 3. Electronic fish mixer.

2.1.4 Ultrasonic Bath

The ultrasonic bath with temperature and time adjustment features is shown in Figure 4.

Figure 4. Ultrasonic bath.

2.1.5 Beaker and Funnel

The beaker and funnel used to separate the pure water from the particles before drying to obtain the nanoparticles are given in Figure 5.

Figure 5. Beaker and Funnel.

2.1.6 High Temperature Regulated Oven

The high temperature regulated oven used to dry the particles at high temperature is shown in Figure 6.

Figure 6. High temperature regulated oven.

2.2 SEM Device Preparation Unit (Coating)

The material to be examined in the SEM device is made ready by coating. The SEM device preparation unit is given in Figure 7.

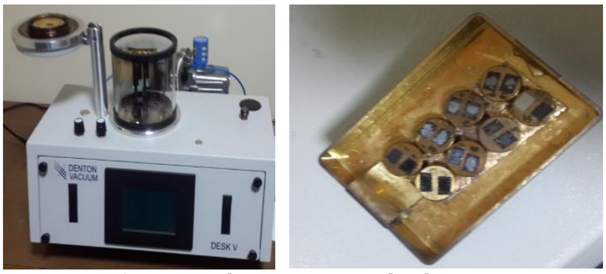

Figure 7. High temperature regulated oven.

2.3 SEM Device

Scanning Electron Microscope (SEM), which is produced in line with electrooptic principles, is one of the devices that serve the purpose of whether the particles are nanoparticles or not. In addition to its use in research and development studies in many fields, Scanning Electron Microscope is frequently used in chip production in microelectronics, error analysis in different branches of industry, biological sciences, medicine and criminal applications. The SEM device is given in Figure 8.

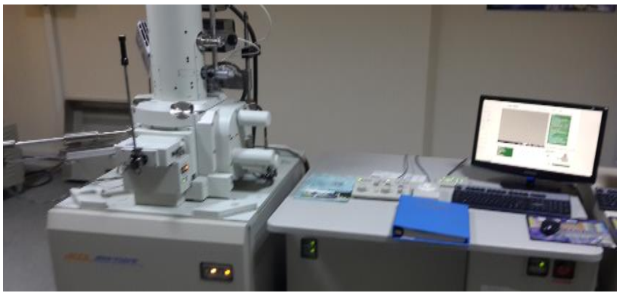

Figure 8. SEM device.

The materials for the production of Al_2O_3 and CuO nanoparticles were prepared in the following proportions. For the production of Al_2O_3 10.8 grams (0.1 mol) aluminum and CuO nanoparticles, first 8.5 grams (0.1 mol) Al_2O_3 and copper acetate are dissolved in 500 ml ethanol for 30 minutes in an ultrasonic bath. Then 40 grams (1 mol) NaOH (sodium hydroxide) dissolves in 200 ml distilled water for 30 minutes in an ultrasonic bath. Finally, these mixtures are combined and stirred in a fish mixer for 1 hour. Then ammonia was added to the mixture in 50 ml beakers to obtain the mixture at various pHs. pH ratios were obtained. After the mixture was prepared, it was left to precipitate for 20 hours. At the end of the waiting process, filter paper was placed and after filtering in funnels, the material was subjected to drying at 50 ^oC. Finally, after the material was heat treated at 470 ^oC for 1 hour, our material was ready. For this reason, there are parameters that are important in the synthesis process when producing particles. These parameters are the material ratios used, the reaction time in the fish mixer in terms of homogeneity of the solution and the heat treatment time to which the material is subjected. As a result of the analysis of the nanoparticles produced in our study, the accuracy of the mentioned parameters was observed as it was seen that the production was successfully realized.

2.4. SEM Images of Materials

SEM images of the nanoparticle types produced are given in Figure 9 and Figure 10.

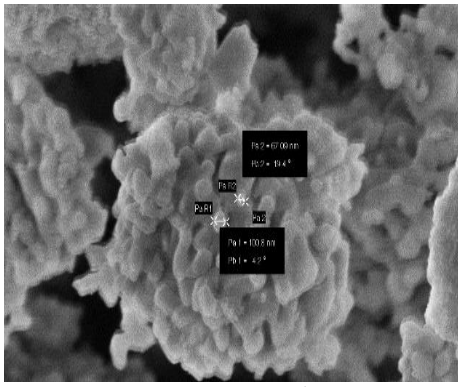

Figure 9. SEM image of Al_2O_3.

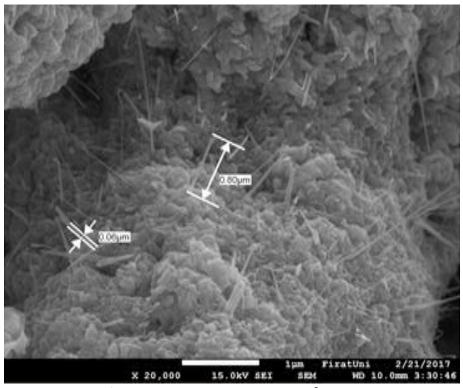

Figure 10. SEM image of CuO.

SEM analysis showed that the nanoparticles produced were successful.

2.5. Thermal Conductivity Measurements of Nanoparticles

Thermal conductivity measurements were performed after nanoparticle production. TLS-100 thermal conductivity measurement device was used for thermal conductivity determinations. Knowing the thermal properties of materials is very important in achieving optimum performance where the material is used. Thermal conductivity is one of the most important thermophysical properties used to define the heat transport properties of materials. With the thermal conductivity analyzer, the thermal conductivity constant values (k) of materials can be determined in W/mK. The surface of the material is brought into contact with the sensor of the device and the thermal conductivity coefficient of the material is determined from the temperature interaction between the sensor and the sample. The schematic image of the device used is shown in Figure 11.

Figure 11. TLS-100 Thermal conductivity meter.

The thermal conductivity coefficients of the Al_2O_3 and CuO nanoparticles we produced were determined using the TLS-100 thermal conductivity meter. The uncertainty of the measuring instrument used is less than 5%. The heat transfer coefficients are given in Figure 12.

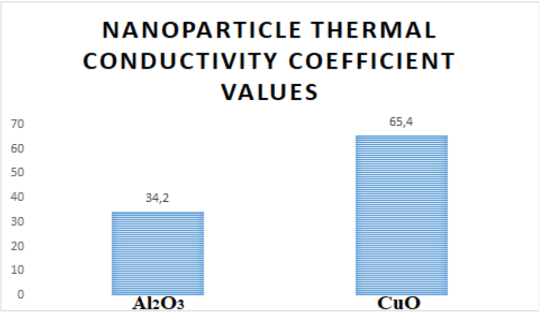

Figure 12. Heat Transmission Coefficients (W/mK) of the metal oxide types produced.

The nanoparticle types for which conductivity measurements were completed were compared with the literature. The nanoparticle types observed in the literature are given in Figure 13 [16].

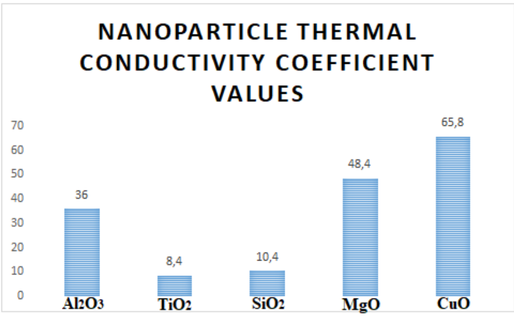

Figure 13. Heat Transmission Coefficients of metal oxide types in literature (W/mK).

3 Conclusion

As a result of the studies examined, it was understood that the use of nanoparticulate materials in the field of thermal insulation can make great contributions to energy saving, as well as having great economic benefits due to the lower cost of nanoparticles and the possibility of more production at low cost. Nanoparticles, which are easy to produce, transport and reach the desired properties due to their structure, have been a type of material that has attracted the attention of the whole world and has been the subject of many studies with its energy saving during the production phase, being economical and saving time by shortening the production time. In our research, the thermal conductivities of the nanoparticles produced by us were determined in terms of evaluating the use of nanoparticle materials, which are a new perspective on energy saving, in thermal insulation materials. Then, the thermal conductivity coefficients of the nanoparticles in the literature were investigated and compared with the values of the nanoparticles produced by us, and the suitability of the use of the nanomaterials we produced in insulation materials was evaluated. In the study, the heat transfer coefficients of Al_2O_3 and CuO nanoparticles were found to be 34.2 and 65.4 W/mK, respectively. In the literature review, it was seen that these values were 36 and 65.8, respectively. As a result of the evaluations, it was observed that the CuO nanoparticle produced by us gave similar results with the literature, and the Al_2O_3 nanoparticle gave better results than similar studies at a rate of 5%. The synthesis of nanoparticles produced under laboratory conditions involves a long and challenging process. In the age of developing and rapidly growing technology, it is seen that particle production is progressing day by day. In the coming years, it is thought that industrial mass production will be started as the fruit of scientific research.

Declaration

Ethics committee approval is not required.

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