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Simulation of municipal solid waste gasification in fixed bed reactor

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Summary. The objective of this work is simulating municipal solid waste gasification in fixed bed reactor. A comprehensive process model developed to simulate municipal solid waste (MSW) gasification in fixed bed reactor using an Aspen Plus simulation .To predict and analyze the municipal solid waste pyrolysis and gasification process in an updraft fixed bed more veritably and appropriately, numerical modeling based on Gibbs energy minimization was executed using the Aspen plus software v(9). Rstoic is a block that can be used to simulate a reactor with the unknown or unimportant reaction kinetic that will describe drying section(moisture evaporated).The Ryield model was describe the pyrolysis section, while the Rgibbs model was used for gasification section individually .The proposed model is used to forecast and analyze target performance parameter including syngas composition, lower heating value and carbon conversion rate under different conditions of gasification temperature , and ratios. The results indicate that is a good agreement between data and simulated data obtained using this model .The predicted optimum gasification temperature is about approximately 750°C, and the best ratio of air equivalent ratio is around 0.2 and feed rate 200 kg /hr..

Keywords: Simulation, Municipal solid, Gasification, Fixed bed reactor, Pyrolysis, Gibbs energy, Rgibbs model, Gasifier

Introduction

Municipal solid waste (MSW), commonly known as trash or garbage in the United State and as refuse or rubbish in Britain, is a waste type consisting of everyday items that are discarded by the public. "Garbage" can also refer specifically to food waste, as in a garbage disposal; the two are sometimes collected separately [1]. Gasification of municipal solid waste (MSW) is a chemical process that generates a gaseous, fuel-rich product. This product can then be combusted in a boiler, producing steam for power generation. Just as with combustion of MSW, MSW gasification does not necessarily compete with recycling programs, but should be considered complementary in any generically constructed MSW plan [2]. This study proposes a model of syngas production from municipal solid waste gasification with air in fixed bed reactors. The model [using Aspen plus simulator [v9] is used to predict the results of MSW gasification and to provide some process fundamentals concerning syngas production from MSW gasification. The effects of gasification temperature, air equivalence ratio and moisture concentration on the composition of syngas, lower heating value [LHV] of syngas, heat conversion efficiency and carbon conversion will discuss.

The results maybe indicate higher temperature improves gasification, and higher air Equivalence ratio increases the carbon conversion while decreasing syngas LHV, Heat conversion efficiency increases, reaches the maximum, and then decreases with the increase of air equivalence ratio, higher moisture concentration increases the carbon conversion and increases the heat conversion efficiency at lower ratios. Higher temperature and a lower equivalence ratio are Favorable for obtaining a higher LHV of syngas at the same moisture concentration [3]. Municipal solid waste gasification has Advantages of energy recovery and weight/ volume reduction. However, as environmental protection becomes more and more important the emission control on MSW incineration is also increasingly important .To provide a more energy efficient and environmentally friendly solution, the study of a novel MSW thermal treatment [gasification of MSW] has gained importance in late time in all over the world except Sudan because there is little information and technology about gasification. Gasification has the advantage like lower dioxins, compared to other disposal options , such as incineration. Too many analysts gasification is expected to be the future method of producing an energy carrier, and the production of syngas from biomass or solid waste would require [3,4]. There are mainly two kinds of gasifier: 1-Fluidized bed gasifier.2-Fixed bed gasifier.

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Fluidized bed gasifier: Gasification by this gasifier is often adopted for larger capacity of MSW disposal. Fluidized bed gasification is more complicated in constructing and operating, and also requires a higher investment [4]. However, in the countries or towns like Sudan [less skill full& info in gasification operation], the output of MSW is not large enough to match the capacity of the fluidized bed, as result for disposing MSW.

Fixed bed gasifier: it is more advisable to choose fixed bed gasification, which requires lower investment, and matches the small output of MSW in these places. Fixed bed gasification also has the advantage of a small amount of fly ash, and the syngas from MSW gasification can be used in various areas as clean energy Corresponding to another reactors. However, most of these fixed bed reactors are used to deal with biomass. To study MSW gasification in real fixed bed reactors, the first step is simulating the process to understand the characteristics of MSW gasification. In this study, a novel process of air gasification of MSW in a fixed bed reactor is proposed. Aspen plus is adopted to simulate the entire process [3]. The process simulation is conducted to demonstrate the possibly available efficiencies of a fixed bed, and evaluate the effects of air equivalence ratio, moisture concentration and gasifier temperature on the LHV of syngas, the composition of syngas, heat conversion efficiency, and carbon conversion of MSW. the increasing amount of MSW have brought great trouble to the economic development. Most of the areas, specially undeveloped areas use landfill as the main disposal option for MSW. But the cites have developed rapidly since the last decade, and landfill is longer economic because the land around cites have become more expensive. MSW has been recognized as type of fuel [4]. Incineration has considered begin useful technology for MSW treatment since it can reduce the weight and volume of MSW and can also get energy recovery from MSW. However, this technology has still not been accepted by most of people because of the emissions, especially the PCDD/Fs from MSW incineration, And communities have heard and concerns about waste incinerators in other localities, even though these are often older inefficient designs not the state-of-the-art technologies which could be used. Nevertheless, gasification has the advantage of lower emissions, compared to MSW incineration [8]. To provide a more energy efficient and environmental friendly solution, the study of gasification has attracted great interest. The syngas from gasification can be used directly or stored and it is expected to be a future energy carrier. As we mentioned before Gasification of MSW or biomass is mainly processed in two types of reactors [7], for larger capacity MSW treatment However, fluidized bed requires more investment while fixed bed requires less investment and it is more suitable for smaller capacity of MSW treatment. As a result, fixed bed is more suitable in a countries and towns which have a relatively smaller MSW yield. There are mainly two types of fixed bed reactors: updraft fixed bed reactor and downdraft fixed bed reactor[gasifier], From the review of gasification in fixed bed it can be found that updraft gasifier have the advantages of high reliability, high efficiency, low specific emissions and feedstock flexibility and the disadvantage of high tar content which can be solved when the gasifier are used for thermal applications. Downdraft gasifier have the advantage of relatively low tar content, however, the tar from downdraft gasifier is more stable than that from updraft gasifier and that may still result in problems in tar removal and the internal heat exchange is not as efficient as in the updraft gasifier On the other hand, downdraft gasifier have the disadvantages of narrow specifications of both feedstock size and moisture content, and limited capacity which may not be suitable for disposing the relatively high yield of MSW from a countries and towns. In summary, it can be concluded that updraft fixed bed reactors are more suitable for MSW gasification in countries and towns especially Sudanese town [4].

Materials and Methods

Municipal solid waste (MSW), commonly known as trash or garbage (US), refuse or rubbish (UK) is waste type consisting of everyday items that are discarded by the public. The composition of municipal waste varies greatly from country to country and changes significantly with time. In countries, which have developed recycling culture, the waste stream consists mainly of intractable wastes such as plastic film, and un-recyclable packaging. In developed countries without significant recycling it predominantly includes food wastes, yard wastes, containers and product packaging, and other miscellaneous wastes from residential, commercial, Institutional, and industrial sources. Most definitions of municipal solid waste do not include industrial wastes, agricultural wastes, medical waste, radioactive waste or sewage sludge. With rising urbanization and change in lifestyle and food habits, the amount of municipal solid waste has been increasing rapidly and its composition changing. Solid waste can be classified into different types depending on their source: a) Household waste is generally classified as municipal waste, b) Industrial waste such as hazardous waste. c) Biomedical waste or hospital waste such as infectious waste.

The fixed bed type reactor for gasification of municipal solid waste basically consists of four stages:

1-Drying, 2-Pyrolysis, 3-Gasification, 4-Combustion,

Fixed bed reactors are used almost in all the chemical plants for one or other reactions, Packed bed type of reactors is one very popular kind than fixed bed reactors. In our process, we are using the fixed bed to gasify the municipal solid waste, In the way function are further divided as updraft and downdraft types of gasifier, They have been explained below .An updraft gasifier has clearly defined zones for partial combustion, reduction, and pyrolysis, air is introduced at the bottom and act as countercurrent to fuel flow, The gas is drawn at higher location, The updraft gasifier achieves the highest efficiency as the hot gas passes through fuel bed and leaves the gasifier at low temperature. The sensible heat given by gas is used to preheated dry fuel. Disadvantages of updraft gas producer are excessive amount of tar in raw gas and poor loading capability. In the updraft gasifier, gas leaves the gasifier with high tar vapor which may seriously interfere the operation of internal combustion engine.

This problem is minimized in downdraft gasifier, In this type, air is introduced into downward flowing fixed bed or solid fuel sand gas is drawn off at the bottom. lower overall efficiency and difficulties in handling, higher moisture and ash content are common problems in small downdraft gas producers.

Drying: Drying is a mass transfer process consisting of the removal of water or another solvent, by evaporation from solid, semi-solid or liquid. In some products having relatively high initial moisture content, an initial linear reduction of the average product moisture content as a function of time may be observed for a limited time, often known as a "constant drying rate period". Usually, in this period, the surface moisture outside individual particles that is being removed. The drying rate during this period is dependent on the rate of heat transfer to the material being dried. Therefore, the maximum achievable drying rate is considered to be heat-transfer limited. In our process, in the Aspen plus process simulator, Rstoic is a block that can be used to simulate a reactor with the unknown or unimportant reaction kinetic and known stoichiometry by specifying the extent of reaction or the fractional component of the key component. Thus in this simulation, it can be used to simulate the drying process (moisture evaporated).

Pyrolysis: Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures without the participation of oxygen. It involves the simultaneous change of chemical composition and physical phase, and is irreversible. Pyrolysis is a case of thermolysis ,and is most commonly used for organic materials, being therefore one of the processes involved in charring. Pyrolysis process breaks down charcoal and hydrocarbons by indirect heating. Mixture of gas, liquid and solid products is produced but the proportion of each can be varied depending on the reaction conditions. In our process, the reactor block called Ryield can be used to simulate the pyrolysis, since it is used to model a reactor by specifying yield distribution data or correlation when reaction stoichiometry and kinetics are unknown.

Combustion: Combustion or burning is the sequence of exothermic chemical reactions between fuel and an oxidant accompanied by the production of heat and conversion of chemical species. The release of heat can produce light in the form of either glowing or aflame; fuels of interest often include organic compounds (especially hydrocarbons) in the gas, liquid or solid phase. Complete combustion is almost impossible to achieve. In reality, as actual combustion reactions come to equilibrium, a wide variety of major and minor species will be present such as carbon monoxide and pure carbon (soot or ash). Additionally, any combustion in atmospheric air, which is 78% of nitrogen, will also create several forms of nitrogen oxides. The combustion section is introduced after the gasifier and it helps in complete combustion of the unburned carbon to give more flue gas and some residue. This flue gas either can be taken out or be fed back to the gasifier section to increase its efficiency. Rgibbs units used to model this section as it deals with some chemical reactions, thus making the minimization of Gibbs free energy as an important aim.

Gasification: Gasification is partial combustion of the solid biomass to give a low to medium heating value fuel gas and an inert residue. Either oxygen enriched air or oxygen can be used with steam added as a reagent and/or temperature control medium. Relatively high temperatures are achieved of 900–1000oC with air and 1000–1500^{o} C with oxygen. Air gasification is most widely used technology since a single product is formed at high efficiency and without requiring oxygen. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself fuel. Gasification as a thermos-chemical process is defined and limited to combustion and pyrolysis. Rgibbs reactor model can be used for modeling the gasification process as this block will need to minimize Gibbs free energy as well as carry out rigorous reactions and multiphase equilibrium. The main reactions that will be carried out in the gasifier would be:

$$C + O_2 \rightarrow CO_2, \; + \; 393kJ/mol \quad (1)$$

$$C + 1/2O_2 \rightarrow CO, \; + \; 110kJ/mol \quad (2)$$

$$C + CO_2 \rightarrow 2CO, \; - \; 173kJ/mol \quad (3)$$

$$C + H_2O \rightarrow CO + H_2, \text{-}132kJ/mol \quad (4)$$

$$3H_2 + CO \rightarrow CH_4 + H_2O, 206kJ/mol \quad (5)$$

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O, \; - \; 165kJ/mol \quad (6)$$

Analysis of MSW: Analysis of composition characteristics of municipal solid waste was done in south China. Using the MSW [municipal solid waste] sampling and analysis methods, the composition characteristics of MSW in south China were investigated. The results showed that: the average MSW bulk density was 0.22×10(3) kg/m^3. The percentages of water, ash and combustible were 55.0–66.9%, 18.6–30.3% and 69.7–81.4%, respectively. The organic contents were 50.1–58.0%.

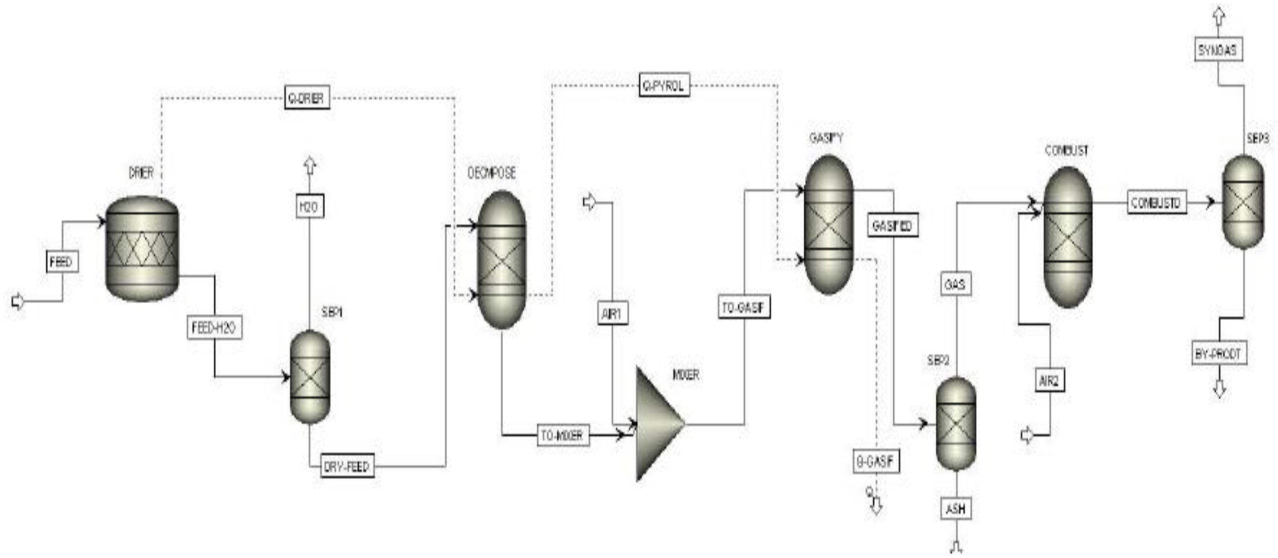

Figure 1. Aspen plus model of MSW

Modeling of MSW: MSW has no strict chemical formula, as it is a mixture of many different materials and has a composition that changes depending on its source. However, the reactor was used in the ASPEN Plus process model using chemical equilibrium calculations to determinate its output compositions, and requires as input feed materials that are of "conventional" type; that is, they must have strict chemical formulas (H_2O, for example) and be well understood, with properties that can be modeled accurately and consistently characterized with data from a data bank. At first glance, MSW does not meet these criteria as an input material.

Characterizing of MSW: A way to characterize the MSW was taken from the coal industry, which has also had to deal with handling heterogeneous materials whose chemical compositions vary from sample to sample. Coal characterization is supported in ASPEN Plus and involves the use of ultimate, proximate, and sulfur analyses. In an ultimate analysis, their C, H, N, O, S, and ash content, on a moisture-free weight percent basis, characterize samples. This analysis plays the primary role in predicting heats of combustion for the MSW. Some representative sets of ultimate analysis data for MSW, taken from a variety of literature sources, are given below in Table I. The widest variation in the data is in the MSW's ash content (5–38%). Data for carbon and oxygen contents vary substantially as well, while the MSW hydrogen content is more consistent across different samples. In a proximate analysis, samples are characterized by their fixed carbon volatile matter," ash, and moisture weight percent. The first three parameters are given on a moisture free basis, and should together total 100%. Any moisture content native to the MSW sample itself is represented by the moisture weight percent. The ratio between the fixed and volatile carbon content for MSW is assumed approximately 1:1 although no MSW proximate analyses were found in the literature MSW is fed from the top into drying section where it is dried by the syngas from pyrolysis section; then the dried MSW is paralyzed in pyrolysis section. The solid products from pyrolysis section are gasified in gasification section with flue gas from combustion section. In combustion section, the gasified solid products are combusted with the air introduced from the bottom. The combusted products in combustion section are residue and flue gas which is go up into the gasification section.

Results and Discussions

Air Equivalence Ratio Effecting on Syngas production: In this study, air equivalence ratio represents the ratio of the amount of introducing air to the amount of air needed for complete combustion. Obviously, vary of air equivalence ratio Therefore, three different reaction conditions can be identified: complete combustion to CO_2, complete gasification to CO and partial combustion [gasification] to CO_2 and CO. This ratio has a strong effect on syngas production. Air equivalence ratio was varied from 0.2 to 1 in this simulation, The gasifier temperature was kept at 750 °C at atmospheric pressure.

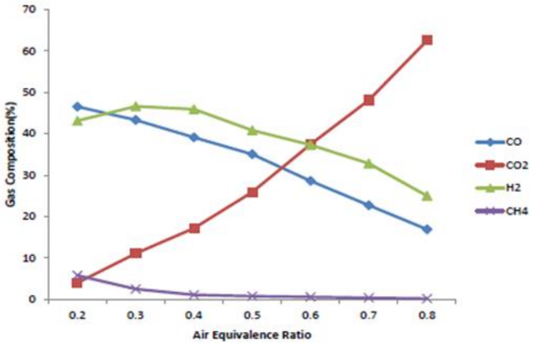

Figure 2. Air Equivalence Ratio v/s Gas Composition Graph

CO_2 concentration increased significantly (from 5 to 60%) with the increase of air equivalence ratio while CO showed an inverse trend (from 47 to 15%) This is because the increase of air equivalence ratio (means more oxygen) placed Eq [1] toward the right At a higher ratio, CO concentration decreased according to Eq. (1) which prevailed over Eq. (2) with the increase of air equivalence ratio. CH_4 concentration decreased as the ratio increase, whilst H_2 concentration decreased according to Eqs. (3) and (6). Concentration would be higher while CH_4 concentration would be lower because a lower CO concentration would place Eqs. (3)–(6) toward right.

Air equivalence Ratio Effecting on LHV of Syngas: Effect of air equivalence ratio on LHV of the syngas is presented in Fig. (2). The LHV (kJ/N m) can be defined as:

$$7\text{-}LHV = (119950.4 \times nH_2 + 10103.9 \times nCO + 50009.3 \times nCH4)/V \quad (7)$$

Where nCO, nH_2 and nCH_4 are the molar yields of CO, H_2, CH_4, respectively, V is the volume of syngas (m3). From Eq. (7), we can see the LHV is dependent on the concentration of combustible gases. It can be concluded from the discussions of syngas composition above that the concentration of combustible gas decreased with the increase of air equivalence ratio. As a result, LHV of the syngas would decrease as the ratio increase and that trend can be found in Figure (3).

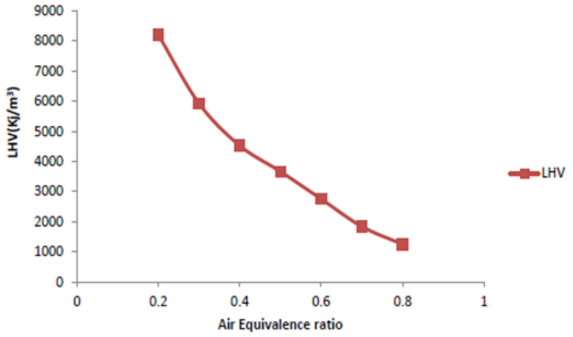

Figure 3. Air Equivalence Ratio v/s LHV Graph

Gasification Temperature Effecting on Syngas Production: The gasification temperature influences the equilibrium of the chemical reactions. In this study, effect of flue gas and gasification temperature on syngas production at an air equivalence ratio of 0.2 was discussed. As shown in Fig. 4, CO concentration increased with the increase of gasification temperature while CO_2 concentration followed an opposed trend. CH_4 concentration decreased slightly as the gasification temperature increased, while H_2 concentration increased slightly with the increase of gasification temperature. These trends can be attributed to the chemical reaction laws, higher temperatures favored the products in endothermic reactions, and favored the reactants in exothermic reactions. Therefore, with the increase of temperature, the decrease of CH4 concentration could be ascribed to the endothermic reaction (5) and (6). The increase of H2 concentration could be explained by the endothermic reaction (4)–(6), and CO concentration would increase because endothermic reaction (3)–(5) are more dominant than exothermic reaction Eq. (2) Although endothermic reaction Eq. (6) releases (and the CO_2 concentration should increase), the CO_2 concentration decreased as the temperature increased. This is because endothermic reaction Eq. (3) was more dominant, placing the reaction toward the right, and resulting in the increase of CO and decrease of CO_2 as the temperature increased.

Gasification Temperature Effecting on LHV: Figure (5) shows that the LHV increased with the increase of gasification temperature. The highest LHV was about 8000 kJ/m^3 at 700 °C.

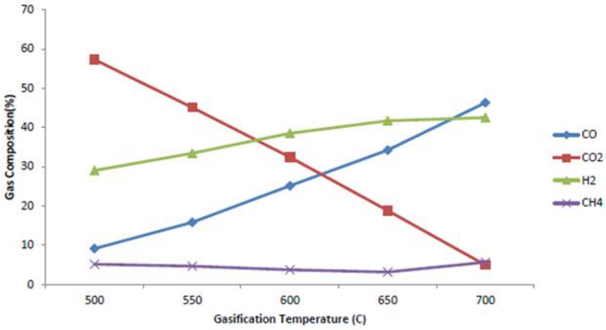

Figure 4. Gasification temperature v/s Gas Composition

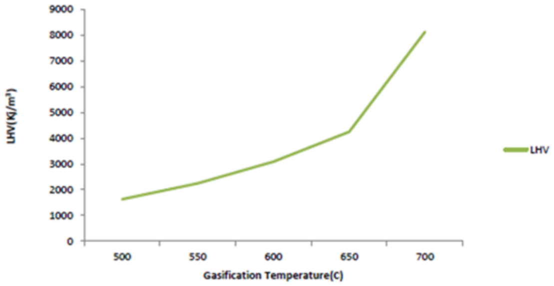

Figure 5. Gasification temperature v/s LHV

Increasing gasification temperature led to an increase of heat conversion efficiency and carbon conversion. These trends can be explained by that the increase of gasification temperature in both types would place the endothermic reaction (3)–(5) toward right which result in the increase of carbon conversion and heat conversion efficiency. And with the increase of gasification temperature, the Introduction of flue gas CO_2 would result in more CO according to Eq. (3) that means higher carbon conversion and heat conversion efficiency.

Conclusion

1. The Air equivalence ratio was found to be highly affecting the output gas composition and LHV. The best ratio was determined to be 0.2.

2. As the increase of the air equivalence ratio, the amount of CO_2 also increases, which has no significant heating value.

3. The gasification temperature was a major factor in syngas production. The CO_2 gas decreased as well as the CO and H_2 gas showed significant increase, but the amount of CH_4 was more or less constant.

4. The carbon conversion efficiency was seen to be almost constant at all equivalence ratios, but the heat conversion efficiency decreased with increasing air equivalence ratio.

5. The gasification temperature also had an effect on LHV of the gas as well as on its Carbon conversion and Heat conversion efficiencies. They all seemed to respond well to the increasing temperature of gasification

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Contribution

Elrafie A.A. Allah corrected the manuscript, improved the results discussion and put in the format required by the Journal before filing in editing.

Yasir A. Mohamed proposed a scheme of the experiments and organized production trials, corrected the manuscript, improved the results discussion and put in the format required by the Journal before filing in editing and is responsible for plagiarism

A. Elhameed. M.O. Kasif corrected the manuscript, improved the results discussion and put in the format required by the Journal before filing in editing and is responsible for plagiarism.

Salah Aldeen A. M. review of the literature on the investigated problem, conducted the experiments, performed the characterizations and measurements, and wrote the manuscript

Conflict of interest

The authors declare no conflict of interest.

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