Applied Thermal Engineering 134 (2018) 29–38

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Investigation on an innovative sorption system to reduce nitrogen oxides of diesel engine by using carbon nanoparticle

L. Jiang[a,b,*], X.L. Xie[b], L.W. Wang[a], R.Z. Wang[a], Y.D. Wang[b], A.P. Roskilly[b]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Sir Joseph Swan Centre for Energy Research, Newcastle University, Newcastle NE1 7RU, UK

HIGHLIGHTS

- An innovative sorption system is proposed to reduce nitrogen oxides emission.
- Nanoparticle of carbon coated aluminum plays dual roles in the beginning and end of this system.
- The lowest annual required mass of composite sorbent is one quarter of that of urea solution.
- Cost of sorption SCR system by using carbon coated aluminum is much lower than that of adblue.

ARTICLE INFO

Keywords:
Selective catalytic reduction
Carbon coated aluminum
Sorption
Composite sorbent

ABSTRACT

A novel sorption system is proposed to reduce nitrogen oxides (NO_x) emission, which is regarded as an alternative solution to conventional urea selective catalytic reduction (SCR) technology. Nanoparticle, i.e. carbon coated aluminum (Al@C) plays dual roles at the beginning and end of this system. One is used to prepare novel fuel blend, which is expected to reduce NO_x emission due to low fuel consumption. The other is selected for developing composite sorbent for ammonia storage reactor. NO_x emission of a diesel engine is tested in terms of various fuel blends. Based on these testing results, working performance of novel sorption SCR system is evaluated. It is indicated that the lowest annual required mass of composite $SrCl_2$ with Al@C is about 98 kg, which is one quarter of urea solution. Comparably, the highest annual required volume of urea solution is 25.6% higher than that of composite $SrCl_2$ with Al@C. Annual required mass ranges from 98 kg to 475 kg whereas annual required volume is in the range from 243 L to 446 L. Feasibility of novel sorption SCR system is further verified, which reveals vast potentials for reducing NO_x emission in terms of conversion efficiency and cost.

1. Introduction

Since the issue of Volkswagen emissions violation, nitrogen oxides (NO_x) emissions have once again become a hot topic which attracts burgeoning numbers of attentions. NO_x emissions of diesel engine have been verified as a major source for air pollution, which contributes to the formation of smog and acid rain [1]. Thus reducing NO_x emissions has become an urgent challenge for environmental protection and energy saving.

It is extensively acknowledged that fuel is not only characterized as power of vehicles but also source of emissions [2]. Thus there are two feasible approaches to realize effective NO_x reduction. One is to decrease the production of NO_x inside engine whereas the other is to take reaction to reduce its emissions. For former methods, exhaust gas recirculation (EGR) [3,4] is generally considered as a mature technology. Since the exhaust gas replaces some of the excess oxygen in the pre-combustion mixture, it inhibits the production of NO_x. Nonetheless, combustion efficiency of diesel engine is more or less influenced in terms of various working conditions. Also worth noting that development of novel fuel blends by using nanoparticles have been investigated by various researchers for reducing NO_x emissions. Soukht Saraee et al. [5] explored the function of blending cerium oxide and cerium dioxide on engine performance. It was indicated that brake specific fuel consumption and NO_x emissions were decreased by adding nanoparticles. Although nanoparticles have an positive influence on NO_x emissions, the limited improvement could be accomplished, which is usually less than 5% [6]. Another method to reduce NO_x emission is to use dual fuel for diesel engine, i.e. ammonia will take effect inside engine. Reiter et al. [7] investigated combustion and emission characteristics of a compression-ignition engine through a dual fuel approach. It was

* Corresponding author at: Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China.
E-mail address: maomaojianglong@sjtu.edu.cn (L. Jiang).

https://doi.org/10.1016/j.applthermaleng.2018.01.116
Received 31 August 2017; Received in revised form 18 November 2017; Accepted 29 January 2018
Available online 31 January 2018

Nomenclature

Adblue	urea solution
Al@C	carbon coated aluminum
BMEP	brake mean effective pressure
B0	diesel
B0E4	diesel with 4% ethanol
B0E4N30	diesel with 4% ethanol and 30 ppm Al@C
EGR	exhaust gas recirculation
ENG	expanded natural graphite
MTS	middle temperature salt
LTS	low temperature salt
NH_3	ammonia
NO_x	nitrogen oxides
Ni@C	carbon coated nickel
Q	heat (kW)
SCR	selective catalytic reduction
TEM	transmission electron microscope

Greek letters

Δx	cycle sorption capacity ($kg^{-1}\,kg^{-1}$)

Subscripts

am	ammonia
c	cycle
de	desorption
eq	equilibrium
eva	evaporation
h	high
i	theoretical
l	low
max	maximum
R	reaction
r	real situation
s	sorption
sor	sorbent

demonstrated that combustion efficiency and emissions were improved by adopting direct ammonia/diesel injection strategies. Later, fumigation of the premixed ammonia was attempted to be applied for a diesel engine. Simulation results revealed that NO_x emissions decreased with little ammonia fumigation and increased with high ammonia fumigation [8]. At present, dual fuel technology for diesel engine mainly concentrates on numerical simulation. It may take a long time to realize real application since the engine is inevitably modified.

From above summary, it is difficult to remarkably reduce NO_x production through improved method in terms of engine part. Thus selective catalytic reduction (SCR) technology is adopted to further reduce NO_x emissions outside engine [9], which is characterized as excellent selectivity with reasonable combustion efficiency remained [10]. For conventional SCR, urea solution (adblue) serves as a source of ammonia to react with NO_x, which will result in some drawbacks, i.e. low ammonia storage density, low NO_x conversion efficiency and crystallization at low ambient temperature [11]. In order to further improve NO_x conversion efficiency, various novel catalysts are developed and investigated in catalytic converter of conventional SCR system. Wang et al. [12] developed a novel Cu-chabazite catalyst, which indicated a significant breakthrough for removing NO_x. Li et al. [13] prepared a novel catalyst with a core-shell structure by using a chemical deposition method. Results demonstrated that the catalyst revealed a relatively high NO conversion efficiency at a temperature range from 110 °C to 220 °C. Due to the limitation of conventional urea SCR system by injecting adblue directly to the catalytic converter, NO_x conversion efficiency could not be further improved only through novel catalysts [14].

Under this scenario, a novel sorption SCR technology is proposed in our previous work, which reveals the advantages of efficient ammonia storage and generation [15]. Monovariant chemisorption reaction process is flexibly adjusted to external conditions by using various metal halides [16], which has been widely applied for various fields such as refrigeration [17], heat pump [18], energy storage [19] and electricity generation [20]. Since ammonia acts as gas form in diesel vehicles, safety of this novel technology could be guaranteed. Composite sorbents have been verified to be a suitable candidate for sorption SCR [21], which could overcome the drawbacks of granular metal chlorides with an improved sorption and desorption characteristic [22]. Recently carbon coated metal and expanded natural graphite (ENG) were investigated as combined additives for enhancing heat and mass transfer performance of composite sorbents [23]. This novel composite sorbents are also expected to have a better performance with regard to sorption SCR technology.

Our previous researches about composite sorbents by using carbon nanoparticles were applied for thermal energy storage. In this paper, a

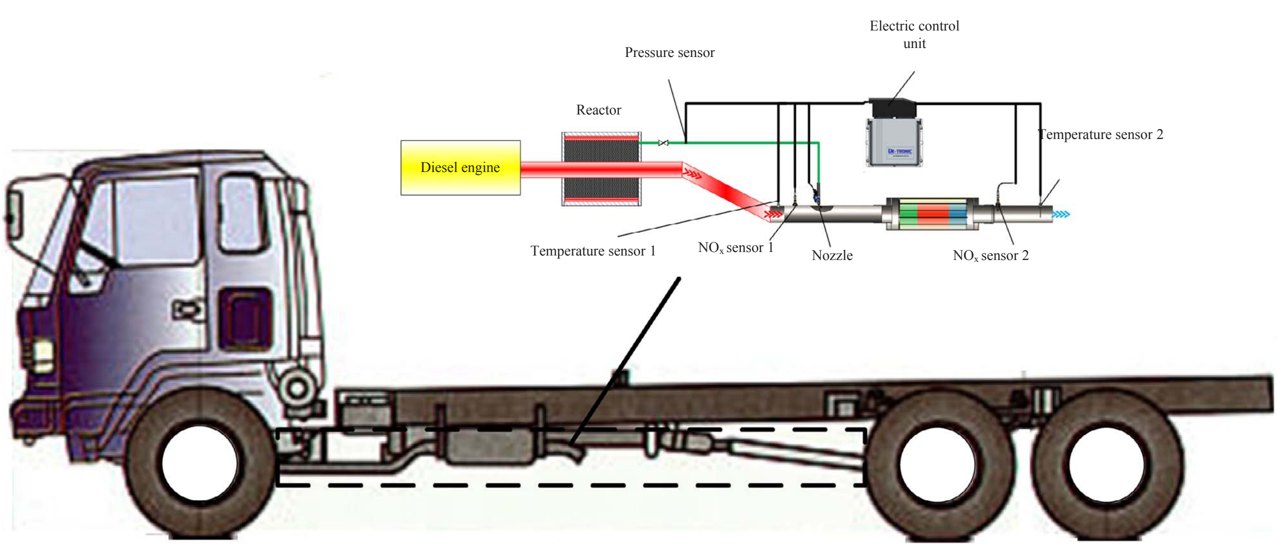

Fig. 1. Layout of novel sorption SCR system in diesel vehicle.