STUDY OF UREA BASED SELECTIVE NON-CATALYTIC REDUCTION OF NO_x IN SMALL SCALE COMBUSTION APPLICATIONS

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To my beloved parents, who sacrificed a lot

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ABSTRACT

Selective Non-Catalytic Reduction (SNCR) of nitric oxide was studied experimentally by injecting different concentrations of aqueous urea solution in a pilot-scale diesel fired tunnel furnace at 3-4 % excess oxygen level and with low ppm of baseline NO_x ranged from 65 to 75 ppm within the investigated temperature range. The furnace simulated small-scale combustion systems such as low capacity boilers, hot water heaters, oil heaters, etc., where the operating temperatures are usually in the range of about 973 to 1323 K and NO_x emission level remains below 100 ppm. In order to investigate the influence of additive on reduction characteristics, different concentrations of commercial grade sodium carbonate (Na_2CO_3) were added to urea solution. The significant aspects of the studies are that it employed commercial grade urea as NO_x reducing agent and commercial grade Na_2CO_3 as additive to urea solution to minimize the cost of the SNCR operation. NO_x reductions were studied with the variation of different parameters such as injection temperature, residence time, Normalized Stoichiometric Ratio (NSR) of the reagent, carrier gas pressure, etc. A significant amount of NO_x reduction was achieved which was not pronounced by the previous researchers with urea SNCR for this low ppm of NO_x. With 5% plain urea solution, at an NSR of 4 as much as 54% reduction was achieved at 1128 K, whilst in the additive case the NO_x reduction was improved to as much as 69% at 1093 K. Apart from this improvement, in the additive case, the effective temperature window as well as peak temperature of NO_x reduction shifted towards lower temperatures. The ammonia slip measurements showed that in both cases the slip was below 16 ppm at NSR of 3 and optimum temperature of NO_x reduction. Finally, the investigations demonstrated that urea based SNCR is quite applicable to small-scale combustion applications and commercial grade urea and sodium carbonate are potential NO_x reducing agent and additive respectively.

ABSTRAK

Satu kajian mengenai Penurunan Bukan Bermangkin Terpilih (SNCR) terhadap nitrik oksida telah dijalankan secara ujikaji dengan menyembur larutan akues urea yang berbeza kepekatan di dalam sebuah terowang relau disel berskala kecil pada paras lebihan oksigen sebanyak 3-4% serta pada nilai emisi NO_x yang rendah iaitu antara 67-75 ppm dalam julat suhu yang dikaji. Relau yang digunakan mewakili sebuah sistem pembakaran berskala kecil seperti dandang berkapasiti rendah, permanas air, pemanas minyak dan sebagainya, di mana suhu operasi relau pada kebiasaannya adalah di dalam lingkungan 973-1323 K manakala paras emisi NO_x adalah di bawah 100 ppm. Dalam mengkaji kesan penambahan larutan urea bagi mengurangkan emisi, pelbagai kepekatan natrium karbonat (Na_2CO_3) bergred komersial telah ditambah ke dalam larutan urea tersebut. Aspek-Aspek penting yang difokuskan dalam kajian ini adalah penggunaan Na_2CO_3, juga bergred komersial, sebagai bahan tambahan kepada larutan urea, untuk mengurangkan kos operasi SNCR. Kajian ke atas pengurangan NO_x dijalankan dengan mengubah beberapa parameter seperti suhu semburan, masa bermastautin, nilai Nisbah Stoikiometri Ternormal (NSR) bagi reagen, tekanan gas pembawa dan sebagainya. Pengurangan nilai NO_x yang ketara telah diperoleh dalam kajian ini yang mana belum pernah dilaporkan oleh mana-mana penyelidik sebelum ini bagi bahan urea SNCR untuk kadar ppm NO_x yang rendah. Pada nilai NSR bersamaan 4 dengan 5% larutan urea, sebanyak 54% pengurangan NO_x telah diperoleh pada suhu 1128 K, manakala bagi kes penambahan bahan penambah pula, pengurangan NO_x telah meningkat sehingga 69% pada suhu 1093 K. Selain dari pembaikan ini, bagi kes bahan penambah, julat suhu efektif dan suhu maksimum pengurangan NO_x telah berubah ke nilai yang lebih rendah. Dalam kedua-dua kes, didapati nilai ammonia yang tidak bertindakbalas yang telah diukur menunjukkan satu nilai yang rendah iaitu di bawah 16 ppm pada NSR 3 serta pada suhu pengurangan NO_x yang optimum. Akhir sekali, kajian yang telah dijalankan menunjukkan bahawa SNCR berasaskan urea boleh digunakan bagi kegunaan pembakaran berskala kecil, manakala bahan urea serta natrium karbonat yang bergred komersial juga berpotensi sebagai agen pengurangan NO_x serta agen penambah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$^{\circ}C$	-	Degree Celsius
$^{\circ}F$	-	Degree Fahrenheit
ASME	-	American Society of Mechanical Engineers
CN	-	Cyanide
CO	-	Carbon monoxide
CO_2	-	Carbon oxide
d	-	Diameter
FGR	-	Flue Gas Recirculation
gm	-	Gram
GPH	-	Gallon per Hour
H_2	-	Hydrogen
H_2O_2	-	Hydrogen peroxide
H_2SO_4		Sulfuric acid
HCN	-	Hydrogen cyanide
hr	-	Hour
K	-	Kelvin
kJ	-	Kilo Joule
Kmol	-	Kilo mole
kW	-	Kilowatt
LNB	-	Low NO_x Burner
m^3	-	Cubic meter
ml	-	Milliliter
mm	-	Millimeter
MW	-	Megawatt
N_2O	-	Nitrous oxide
Na_2CO_3		Sodium carbonate

NH_3	-	Ammonia
NO	-	Nitric oxide
NO_2	-	Nitrogen dioxide
NO_x	-	Nitrogen oxides
NSR	-	Normalized Stoichiometric Ratio
O_2	-	Oxygen
O_3	-	Ozone
OFA	-	Over Fire Air
ppm	-	Parts Per Million
SCR	-	Selective Catalytic Reduction
$SNCR$	-	Selective Non-Catalytic Reduction
SO_2	-	Sulfur dioxide
T	-	Temperature
VOC	-	Volatile Organic Compound
vol	-	Volume
wt	-	Weight

LIST OF APPENDICES

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