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Calcium oxide: A powerful material for C-C bond-forming reactions

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Abstract
This paper provides review about the utilization of CaO-based catalyst for application in organic synthesis, especially carbonyl condensation reaction. As a result, it can be used for Aldol condensation, Knoevenagel condensation, pyranopyrans, pyridines and indazolophthalazine-triones synthesis.

Keywords: calcium oxide, base catalyst, carbon-carbon bond formation, condensation

Introduction
The construction of new C-C bond is one of the most important reaction in synthetic organic chemistry [1]. Some type of chemical reactions such as Aldol condensation, Knoevenagel condensation and Michael addition are used to give specific products [2]. Particularly, C-C bond-forming reactions that involves carbonyl condensation are of special interest due to the potency of organic products as bioactive molecules [3, 4]. On the other hand, catalyst is a crucial factor that influence the efficacy of certain reaction, including C-C bond formation.
CaO is a basic oxide which can be derived from natural resources [5, 6]. CaO and modified CaO have been largely used as heterogeneous catalyst for biodiesel production as well as removal of hazardous materials and toxic contaminants [7-12]. This paper presented a review concerning the utilization of CaO-based materials for various organic transformation involving carbonyl compounds as substrate of the reaction, with the aim of forming carbon-carbon bond.

Discussion
Aldol Condensation: Tang *et al*. produced chalcones from the reaction between substituted acetophenones and benzaldehydes catalyzed by modified commercial CaO with the best yield 90.5% [13]. They modified CaO by simple treatment using benzyl bromide to increase surface area of the catalyst. Moreover, this research group also reacted substituted aromatic aldehydes with cyclohexanone [14]. Resultantly, by using benzaldehyde as model compound, yield of 95.8% was obtained over modified CaO after 3 h. However, the best yield (99.4%) was recorded when 1-naphtaldehyde mixed with cyclohexanone on the same reaction condition [14]. Recently, Mardiana *et al*. exploited Aldol condensation between substituted acetophenones and benzaldehydes using sodium impregnated on activated chicken eggshells (Na-ACE) [15]. XRD and elemental analyses suggested that the catalyst contains high content of calcium oxide.

Knoevenagel Condensation: In the first step of base-catalyzed reaction, it is characterized by proton abstraction of methylene group. Some basic materials have been developed, such as calcium oxide [16], fly ash supported on calcium oxide (FAC) [17], and calcined eggshells at 900-1000°C (CES) [18]. These materials showed excellent activity for Knoevenagel condensation of substituted aromatic aldehydes and simple active methylene compounds (malononitrile and ethyl 2-cyanoacetate).

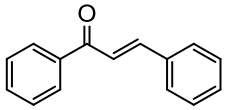
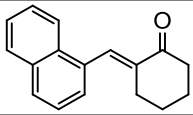
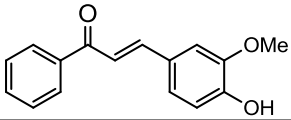
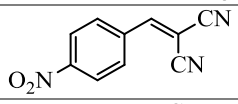
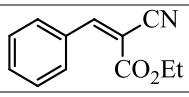
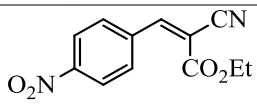
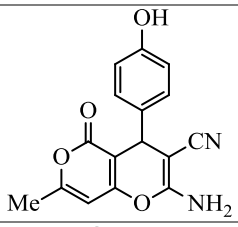
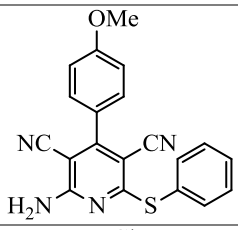
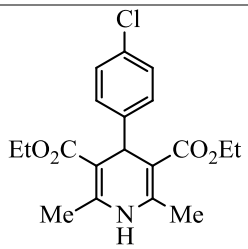
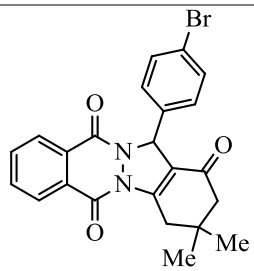
Pyranopyrans Synthesis: Mosaddegh & Hassankhani prepared nano-CaO by calcining ball-milled chicken eggshell waste [19]. It exhibited high activity and recyclability for synthesis of pyrano [4,3-*b*] pyrans via one-pot multicomponent reaction of aromatic aldehydes, malononitrile and 4-hydroxy-6-methyl-2*H*-pyran-2-one under solvent-less condition.

Pyridines Synthesis: Safaei-Ghomi and co-workers successfully synthesized highly substituted pyridines via one-step three-component reaction catalyzed by calcium oxide

nanoparticles (nano-CaO) [20]. Hantzsch condensation for the synthesis of 1,4-dihydropyridines was presented by Morbale and co-authors [21]. Aromatic aldehyde, ethyl acetoacetate/ dimedone and ammonium acetate were mixed in the presence of calcined eggshell waste (10 wt. %).

Indazolophthalazine-triones: Catalytic performance of Ca_2CuO_3/ $CaCu_2O_3$/ CaO nanocomposite was evaluated in the synthesis of 2*H*-indazolo [2,1-*b*] phthalazine-triones [22]. Nanocomposite was prepared via coprecipitation and thermal decomposition techniques using copper(II) sulfate and eggshell waste as low cost precursors. From investigation of the catalytic activity, the multicomponent reaction that employing aromatic aldehyde, dimedone and phthalhydrazide as starting materials was completed within 5-20 min with yield in the range of 80-94% [22].

Table 1: Some Chemical Reactions Catalyzed by CaO-based Materials

Type of Reaction	Catalyst	Product[a]	Yield/ Conversion (%)	[Ref]
Aldol condensation	Modified CaO with benzyl bromide		90.5[b]	[13]
	Modified CaO with benzyl bromide		99.4[b]	[14]
	Na-ACE		95[b]	[15]
Knoevenagel condensation	Commercial CaO		92[b]	[16]
	FAC		87[c]	[17]
	CES		98[b]	[18]
Pyranopyran Synthesis	Nano-CaO based on eggshell waste		98[b]	[19]
Pyridine Synthesis	Nano-CaO		92[b]	[20]
	Calcined eggshell		96[b]	[21]
Indazolophtalazinetrione Synthesis	Ca_2CuO_3/ $CaCu_2O_3$/ CaO composite		94[b]	[22]

a. Product obtained in highest yield/ conversion.
b. Yield.
c. Conversion.

Conclusions

The review highlighted that calcium oxide and modified calcium oxide can be used for various carbonyl condensation reaction with high activity.

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