การสังเคราะห์สารกลุ่มไฮโดรควิโนนและเบนโซควิโนนเพื่อเป็นสารต้านออกซิเดชันในน้ำมันหล่อลื่น

นางสาวสลิลทิพย์ ประเทืองสุขศรี

SYNTHESIS OF HYDROQUINONES AND BENZOQUINONES AS ANTIOXIDANTS IN LUBRICANT

Miss Salinthip Prathuangsuksri

Thesis Title   Synthesis of Hydroquinones and Benzoquinones as Antioxidants in Lubricant

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Field of Study   Petrochemistry and Polymer Science

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สลิลทิพย์ ประเทืองสุขศรี : การสังเคราะห์สารกลุ่มไฮโดรควิโนนและเบนโซควิโนนเพื่อ
เป็นสารด้านออกซิเดชันในน้ำมันหล่อลื่น (SYNTHESIS OF HYDROQUINONES
AND BENZOQUINONES AS ANTIOXIDANTS IN LUBRICANT) อ. ที่ปรึกษา:
ผศ. ดร.วรินทร ชวศิริ, 84 หน้า. ISBN 974-17-5973-8.

ได้สังเคราะห์และพิสูจน์โครงสร้างของ 2-แอลคิลไฮโดรควิโนน 21 ชนิด (**H1-H21**) และ 2-
แอลคิล-1,4-เบนโซควิโนน 4 ชนิด (**Q1-Q4**) รวมทั้งค้นหาฤทธิ์ด้านออกซิเดชันในน้ำมันหล่อลื่น
ในบรรดาสารที่สังเคราะห์ได้พบว่าสารกลุ่มไฮโดรควิโนน 9 ชนิด (**H3, H6-H8, H11-H13,
H16** และ **H20**) และกลุ่มเบนโซควิโนน 1 ชนิด (**Q3**) เป็นสารใหม่ ผลการศึกษาฤทธิ์ด้านอนุมูล-
อิสระเบื้องต้นด้วย DPPH radical scavenging assay ชี้ให้เห็นว่าสารกลุ่มไฮโดรควิโนนทั้งหมด
แสดงฤทธิ์ยับยั้งต่ออนุมูลอิสระ DPPH ในระดับสูง โดยสารใหม่ในกลุ่มไฮโดรควิโนน 3 ตัว (**H6,
H7** และ **H12**) แสดงฤทธิ์สูงสุดต่อ DPPH และแสดงฤทธิ์ดีกว่า TBHQ ซึ่งเป็นสารด้าน
ออกซิเดชันทางการค้า เป็นไปได้ว่าเป็นผลจากการเกิดอนุมูลอิสระฟีนอกซิลที่เสถียร ในทางตรง
ข้ามสารสังเคราะห์กลุ่มเบนโซควิโนนไม่มีฤทธิ์ดังกล่าว ในการทดสอบ Rotating Bomb Oxida-
tion Test สารที่มีศักยภาพสามชนิดดังกล่าวยังคงแสดงฤทธิ์ด้านออกซิเดชันสูงกว่า TBHQ สังเกต
จากการชะลอปฏิกิริยาออกซิเดชันในน้ำมันหล่อลื่นพื้นฐานได้ยาวนานกว่า การยับยั้งปฏิกิริยาออก-
ซิเดชันของสารเหล่านี้เกิดขึ้นได้ในระบบวิวิธพันธ์ และไม่ได้รับอิทธิพลจากการละลาย โดยยืนยัน
จากค่า IP ที่เทียบเคียงกันได้ระหว่าง **H9** กับอนุพันธ์ที่มีหมู่ลอริล (**L2**)

สาขาวิชา.... ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์...... ลายมือชื่อนิสิต...................................
ปีการศึกษา.........................2548.................................. ลายมือชื่ออาจารย์ที่ปรึกษา.......................

SALINTHIP PRATHUANGSUKSRI: SYNTHESIS OF HYDROQUINONES AND BENZOQUINONES AS ANTIOXIDANTS IN LUBRICANT. THESIS ADVISOR: ASST. PROF. WARINTHORN CHAVASIRI, Ph.D., 84 pp. ISBN 974-17-5973-8.

Twenty one 2-alkylated hydroquinones (H1-H21) and four 2-alkylated-1,4-benzoquinones (Q1-Q4) were synthesized, characterized and explored for their antioxidant activity in lubricant. Among those synthesized compounds, nine hydroquinones (H3, H6-H8, H11-H13, H16 and H20) and a benzoquinones (Q3) were disclosed to be new compounds. The preliminary antioxidant activity results by DPPH radical scavenging assay pointed out that all synthesized hydroquinones exhibited high activity against scavenging DPPH radicals. Three new hydroquinones (H6, H7 and H12) showed the highest activity toward DPPH and exhibited better activity than TBHQ, a commercial antioxidant, possibly due to the formation of more stable phenoxyl radicals. On the contrary, synthesized benzoquinones had no activity. In Rotating Bomb Oxidation Test, three potent aforementioned compounds displayed antioxidant activity more than TBHQ observing from the longer period (IP value) for delaying autoxidation of base oils. The autoxidation inhibition of these compounds can occur in heterogeneous system and is not influenced by solubility confirmed by comparable IP values between H9 and its analogues bearing a lauryl group (L2).

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Field of study Petrochemistry and Polymer Science Student's signature ....

Academic year ....2005 ....Advisor's signature....................

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

A	absorbance
br	broad (IR)
δ	chemical shift
J	coupling constant (NMR)
cm^{-1}	wavenumber
^{o}C	degree celsius
CDCl$_3$	deuterated chloroform
CH$_2$Cl$_2$	dichloromethane, methylene chloride
DMF	dimethylformamide
DMSO	dimethylsulfoxide
DPPH	2,2-diphenyl-1-picrylhydrazyl
d	doublet (NMR)
dd	doublets of doublet (NMR)
EtOAc	ethyl acetate
g	gram(s)
Hz	hertz
hr	hour(s)
IC$_{50}$	50% inhibitory concentration
IP	induction period
IR	infrared
KBr	potassium bromide
LiCl	lithium chloride
m	medium (IR)
m.p.	melting point
mL	milliliter(s)
mM	millimolar
mmol	millimole

mg	milligram(s)
min	minute(s)
m	multiplet (NMR)
nm	nanometer
NMR	nuclear magnetic resonance
ppm	part per million
quin	quintet (NMR)
R_f	retardation factor
s	singlet (NMR)
s	strong (IR)
str	stretching
TLC	thin layer chromatography
t	triplet (NMR)
λ	wavelength
w	weak (IR)
%w/w	percent of weight by weight

CHAPTER I

INTRODUCTION

The most important function of lubricants is the reduction of friction and wear and in some cases the relative movement of two bearing surfaces is only possible if a lubricant is present. During this time, when the world is industrial era, the lubricants play a significant role. This could be illustrated by their growth rate 6.5% between 1997 and 2002 and their consumption. In 1999, 37.3 million tons of lubricants were consumed worldwide, 56% were automotive lubricants, 29% industrial lubricants, 5% marine oils and 10% process oils [1].

On average, lubricating oils quantitatively account for about 90% of lubricant consumption and majority of the oil is mineral oil. They consist of about 93% base oil, which is a mixture of C_{20}-C_{45} hydrocarbons, and 7% chemical additive to provide all the necessary function properties [1].

During the entire lifetime of the lubricating oil, from when it is first produced in the refinery until the moment when it is consumed by machines, the problem of their instability always exists. Lubricating oils are susceptible to oxidation and can be further decomposed by auto-oxidation. The reaction leads to the development of corrosive organic acid and insoluble resinous matter, and a marked increase in viscosity of the oils, all of which seriously impair the efficiency of the oils. The serious problem influenced to the lifetime or stability of the oils [1-5].

1.1 Oxidation of lubricating oils [5]

The auto-oxidation of many liquid and solid hydrocarbons can be represented by series of free-radical reactions involving O_2.

1.1.1 At low temperature (30-120°C)

Self-accelerating oxidation which is called auto-oxidation is driven by an auto-catalytic reaction which can be described by free radical mechanism.

(1) Initiation of the radical chain reaction

The first step of a process is catalyzed by traces of transition metal ions.

$$R-\underset{\underset{H}{|}}{\overset{\overset{CH_3}{|}}{C}}-H \xrightarrow{Mn^+/O_2} R-\underset{\underset{H}{|}}{\overset{\overset{CH_3}{|}}{C}}\bullet \ + \ HOO\bullet \tag{1.1}$$
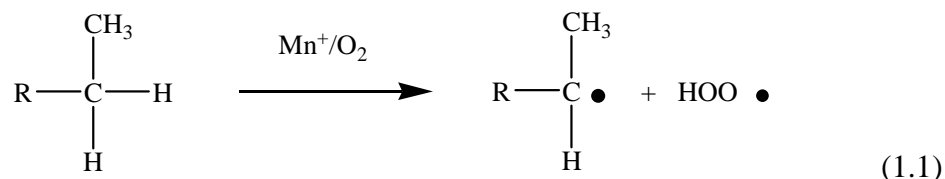
The strength of C-H bond determined the attack site of oxygen.

$$RCH_2\text{-}H \ < \ R_2CH\text{-}H \ < \ R_3C\text{-}H \ < \ RCH=CH(R)HC\text{-}H \ < \ C_6H_5(R)HC\text{-}H \tag{1.2}$$
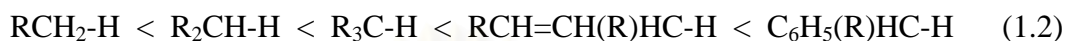
(2) Propagation of the radical chain reaction

Next step, alkyl radical and oxygen combine to form alkyl peroxyl radical.

$$R(CH_3)CH\bullet \ + \ O_2 \longrightarrow R(CH_3)CHOO\bullet \tag{1.3}$$

The reactivity of alkyl radical is depending on types of substituents.

$$CH_3\bullet > C_6H_5(R)CH\bullet > RCH=CH(R)CH\bullet > R_2CH\bullet > R_3C\bullet \tag{1.4}$$

The alkyl peroxyl radical can propagate another hydrocarbon to yield hydroperoxide and alkyl radical which can also combine with oxygen.

$$R(CH_3)CHOO\bullet \ + \ RH \longrightarrow R(CH_3)CHOOH \ + \ R\bullet \tag{1.5}$$
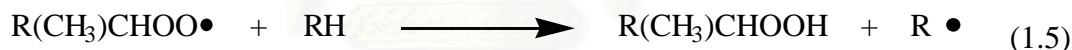
However, the radicals usually react *via* intramolecular abstraction.

$$RHC(CH_2)x-\underset{\underset{O\bullet}{\overset{|}{O}}}{C}(R_2)(R_1) \longrightarrow \ ... \tag{1.6}$$

I (1.6)
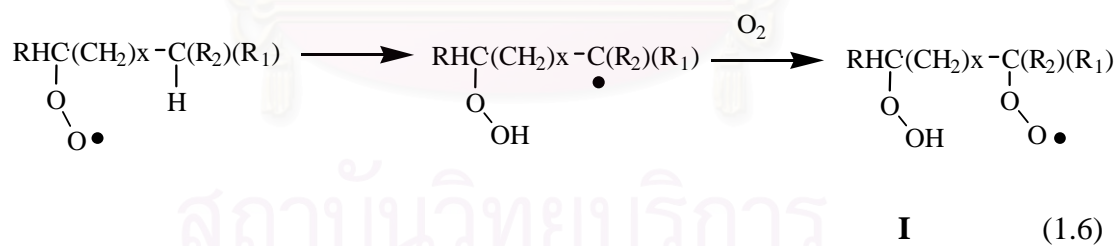
These intramolecular reactions cause to increase hydroperoxide which result in a reinforced auto-catalytic degradation of the hydrocarbons.

(3) Chain branching

Hydroperoxides may cleavage homolytically to yield alkoxyl and hydroxyl radical. The reaction has important role at high temperature or under catalysis conditions.

$$ROOH \longrightarrow RO\bullet \ + \ HO\bullet \tag{1.7}$$

Only hydroxyl and primary alkoxyl radicals are more active and non-selective to hydrogen abstraction.

$$HO\bullet \ + \ CH_3{-}R \longrightarrow H_2O \ + \ RCH_2\bullet \qquad (1.8)$$

$$HO\bullet \ + \ R{-}CH_2{-}R_1 \longrightarrow H_2O \ + \ R(R_1)HC\bullet \qquad (1.9)$$

$$RCH_2O\bullet \ + \ CH_3{-}R \longrightarrow RCH_2OH \ + \ RH_2C\bullet \qquad (1.10)$$
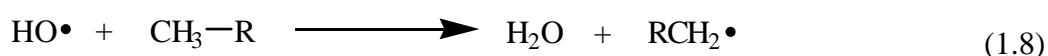
On the other hand, 2° and 3° alkoxyl radicals prefer degradation to form aldehydes and ketones.

$$R{-}\underset{\underset{R_1}{|}}{\overset{\overset{H}{|}}{C}}{-}O\bullet \longrightarrow RCHO \ + \ R_1\bullet \qquad (1.11)$$

$$R_2{-}\underset{\underset{R_3}{|}}{\overset{\overset{R_1}{|}}{C}}{-}O\bullet \longrightarrow R_1COR_2 \ + \ R_3\bullet \qquad (1.12)$$
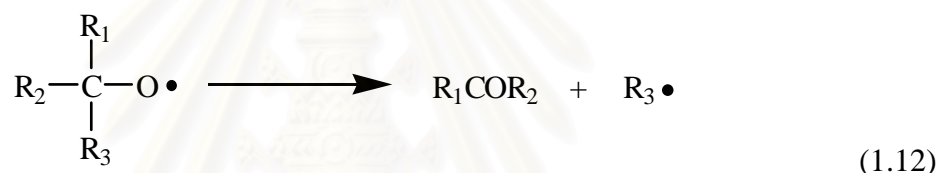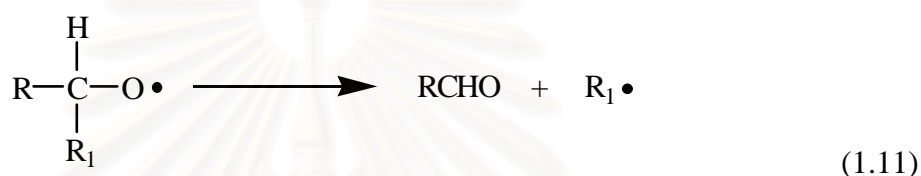
From these reactions, the accumulating of hydroperoxide is caused to increase reactive free radicals that can initiate new chains.

(4) Termination of the radical chain reaction

Only 1° and 2° peroxyl radical will be disproportionated after the combination to non-radical degradation product (*e.g.* ketones and alcohols).

$$2RR_1CHOO\bullet \longrightarrow [R(R_1)CHOOOOCH(R_1)R] \longrightarrow R(R_1)C{=}O \ + \ O_2$$
$$+ \ HO{-}CH(R_1)R \qquad (1.13)$$
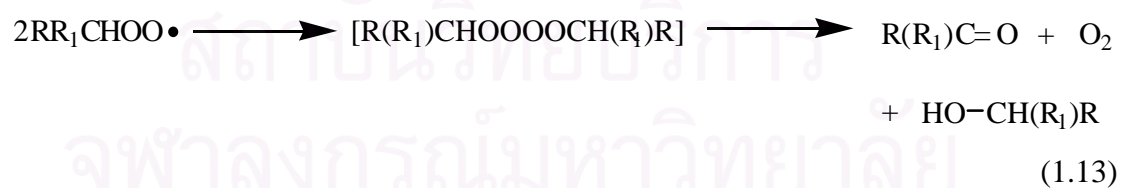
In contrast, 3° peroxyl radicals may either combine and disproportionate to give di-tertiary alkyl peroxides, ketones and alkyl radicals.

$$2RR_1R_2C{-}O\bullet \begin{array}{l} \nearrow RR_1R_2COOCR_2R_1R \\ \\ \searrow 2RR_1C{=}O \ + \ 2R_2\bullet \end{array} \qquad (1.14)$$
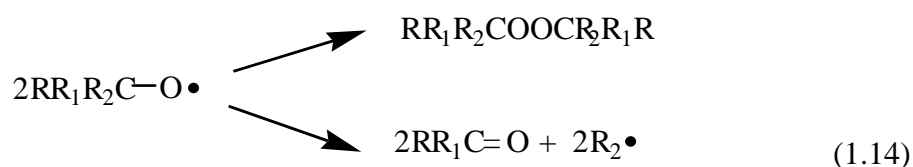
The reactivity of peroxyl radical is followed by:

$$1^o > 2^o > 3^o \quad \text{peroxyl radical} \tag{1.15}$$

In summary, auto-oxidation at low temperature can lead to alkyl hydroperoxides (ROOH), dialkylperoxides (ROOR), alcohols, aldehydes and ketones.

1.1.2 At high temperature (>120°C)

(1) Primary oxidation phase

At high temperature, initiation and propagation steps would take place as same as those occurred at low temperature, but the selectivity was reduced and the reaction rate was increased.

Hydroperoxide-peroxyl radicals (**I**) and aldehydes can cleave to yield carboxylic acid products.

$$\tag{1.16}$$

$$\tag{1.17}$$
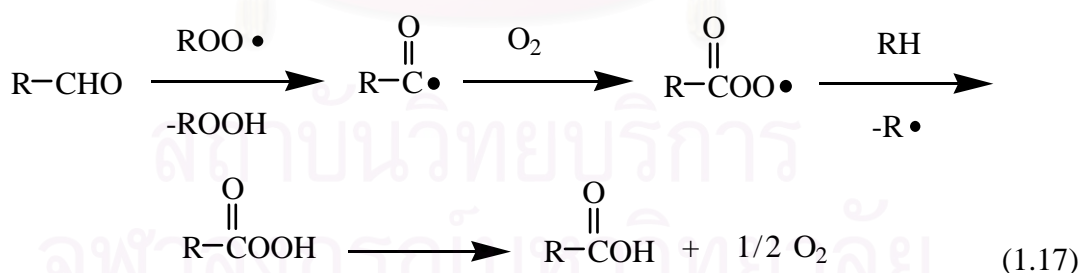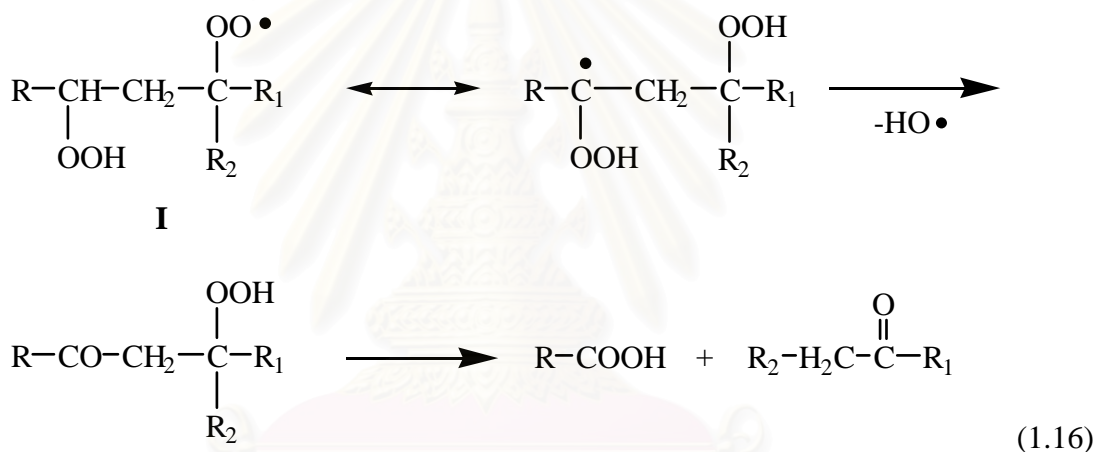
(2) Secondary oxidation phase

At higher temperatures the viscosity of the bulk medium increases as a result of the polycondensation of the difunctional oxygenated products formed in the primary oxidation phase. The polycondensation occurring *via* acid or base-catalyzed aldol condensation lead to high molecular weight intermediates.

$$RCO\text{-}(CH_2)_nCHO + CH_3\text{-}COR_1 \xrightarrow[\text{or base}]{\text{acid}} R\text{-}CO(CH_2)_nCH\text{=}CHCOR_1 + H_2O$$

V

$$V + RCO\text{-}(CH_2)_mCOR_2 \xrightarrow{H_2O} \begin{array}{c} RCO\text{-}C\text{-}(CH_2)_{n-1}CH\text{=}CHCOR_1 \\ \parallel \\ R\text{-}C\text{-}(CH_2)_mCO\text{-}R_2 \end{array}$$

(1.18)

VI
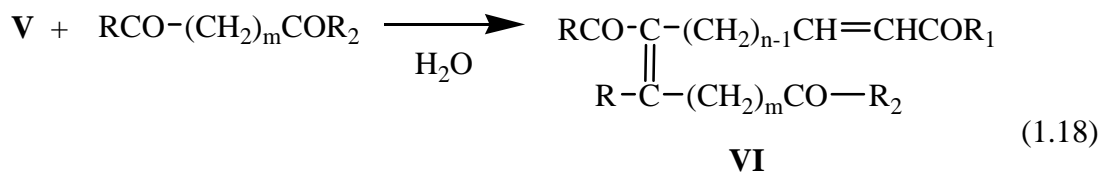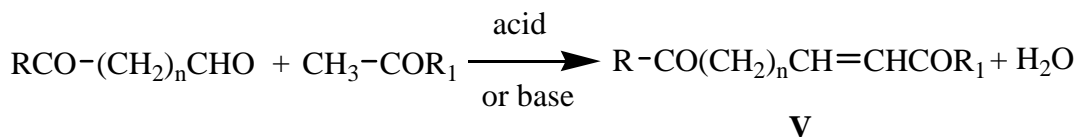
These products are then initiated to copolymerization by alkoxyl radical. This leads to sludge formation that is non soluble product in the oils.

$$x\,R\text{·}CO\text{·}CH_2\text{·}CH_2\text{-}R_1 + y\,CH_3CO\text{-}CH\text{=}CH\text{-}(CH_2)_nCOOR_2$$

$$\xrightarrow{RO\bullet} \begin{array}{c} \left[\begin{array}{cc} CH & CH \\ | & | \\ COR & R_1 \end{array}\right]_x \left[\begin{array}{cc} CH & CH \\ | & | \\ COCH_3 & (CH_2)_n\text{-}COOR_2 \end{array}\right]_y \end{array}$$

(1.19)
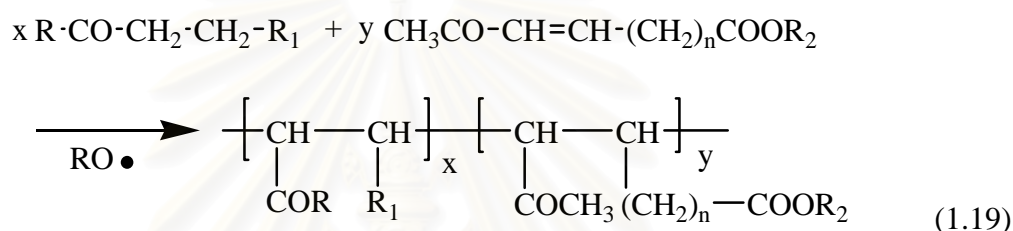
However, under severe conditions, hydrocarbons are possibly occurred *via* thermal cleavage to form low molecular weight and high volatile compounds.

$$R(CH_2)_6R \longrightarrow 2[RCH_2CH_2CH_2\bullet] \longrightarrow 2RCH_2CH\text{=}CH_2 + H_2$$

(1.20)
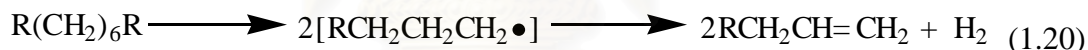
In conclusion, the oxidation at high temperature is strongly influenced by temperature and metal resulting in the formation of sludge and high viscosity oils.

1.2 Phenolic antioxidants

Although modern base oils possess an aging stability which is sufficient for normal demands, it is not sufficient for machinery running under high loads (compressors, gas turbines, gear) or for valuable aggregates or those with large oil charge (transformers, steam turbines, ship gears) to last for the required. This aging process can be delayed tremendously by the use of antioxidants [3].

Antioxidant or oxidation inhibitor is compounds which interrupt the radical chain mechanism of this autoxidation process. They can be classified by the way in which they interfere with the process of the reaction. Two main types can generally be identified: the chain-breaking antioxidants which either reduce the alkylperoxyl

radicals or oxidize the alkyl radicals and the preventive antioxidants which either retard the breakdown of hydroperoxides [3].

Normally, refined mineral base oils contain nitrogen-, sulfur- and oxygen-containing heterocycles as well as mercaptans (RSH), thioether (RSR) and disulfides (RSSR) that may act as so-called 'natural antioxidants' or as pro-oxidants that will accelerate the oxidation of the lubricants [1, 3]. However, such compounds contain in a small quantity. Several synthetic antioxidants are invariably needed to add with the aim of assisting the oil stability. These can be differentiated into two main groups, *i.e.*, primary antioxidants (radical scavengers) and secondary antioxidants (peroxide decomposers). Among them, the phenolic antioxidants are especially considered because they are able to directly seize peroxyl radicals formed during oxidative degradation [6].

Sterically hindered mono-, di- and polynuclear phenol derivatives belong to the most effective antioxidants acting as radical scavengers and used for many applications. Typically the phenols are commonly substituted at 2 and/or 6 positions with tertiary butyl group. The most simple derivatives are 2,6-DTB (2,6-di-*tert*-butylphenol) and BHT (butylated hydroxytoluene) [1].

2,6-DTB   BHT
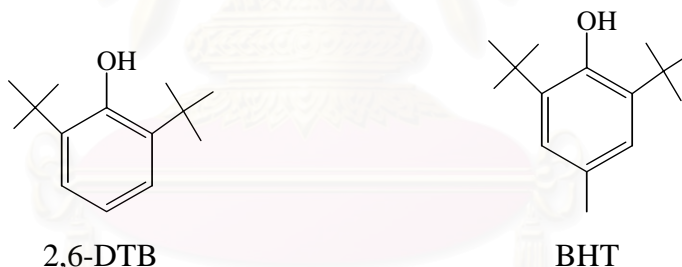
1.2.1 Chain-breaking mechanism of phenolics [7]

Alkyl peroxyl, ROO•, is an electron acceptor and can be readily reduced by electron donor. Therefore, phenols of specific structures function as electron acceptors by transferring of a hydrogen atom from the oxygen atom to peroxyl radical. The radical inhibitors formed would react through radical combination or the other reaction that do not maintain the radical auto-oxidation reaction.

$$RO_2^{\bullet} + ArOH \longrightarrow ROOH + ArO^{\bullet}$$

$$(n-1)\,RO_2^{\bullet} + ArO^{\bullet} \longrightarrow \text{non - radical products} \qquad (1.21)$$
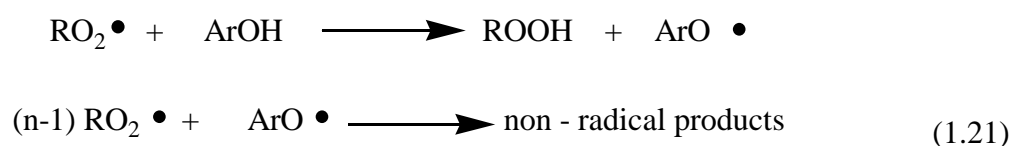
1.2.2 Structure-activity relationships (SARs) [8]

The antioxidative activity of phenols has been reported to have a close relationship with their structures. Their activity is indicated by the total π-electron density of the oxygen atom. It can be assumed that:

- Electron donating groups in the aromatic ring increase antioxidant activity; whereas electron withdrawing groups decrease it.
- Substituents that delocalized the electron in the aryloxyl radicals increase antioxidant activity

These rules can be rationalized on the basis of the transition state involved in hydrogen abstraction by alkyl peroxyl moiety. There is both partial separation of charge between the alkyl peroxyl group and the aromatic ring and partial delocalization of the electron in the π bond system. Thus, groups in X and R_1, R_2 which release electrons or delocalize the unpaired electron decrease the transition state energy.

$$(1.22)$$
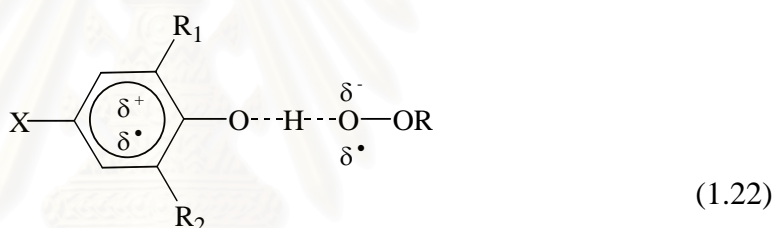
Their relationship has been extensively studied in many research groups. It has been mainly related to type and number of characteristic groups on the aromatic ring. Therefore, various substituents are significantly considered for the effect of phenolic on the antioxidant activity.

For instance, in 1985, Yamada *et al.* [**9**] have studied the antioxidative activities of twenty compounds of four series of benzylphenols, *i.e.*, 4-benzylphenols, 2-methyl-4-benzylphenols, 4-methyl-2-benzylphenols and 4-methoxy-2-benzyl-phenols. These compounds have been prepared, evaluated the antioxidant compared with tetralin at 60°C by means of an oxygen-absorption method. Very good activities have been observed with a series of 4-methoxy-2-benzylphenols. Moreover, they have addressed that the antioxidative activities were closely correlated with both the ^{13}C NMR chemical shift of the *ipso*-carbon of the OH substituent and their peak potentials (E_p) in electrochemistry.

In 1989, Yamada *et al.* [**10**] evaluated the antioxidative activities of nineteen compounds of seven series of alkylidene- and benzylidenebisphenols with an oxygen-

absorption method for tetralin. Series of 2,2′-alkylidene- and benzylidenebis(4,6-dimethylphenol) derivatives have shown very good activities.

In 1995, Yamamura *et al.* [7] studied the antioxidant of dihydric phenols, such as catechol, resorcinol and hydroquinone, and their twenty-three alkyl and benzyl derivatives. All of them were evaluated the antioxidant by means of an oxygen-absorption method at $60^{o}C$. Catechols and hydroquinones were found to be efficient antioxidants. Resorcinol in spite of having two OH substituents behaved as monohydric phenols in the reaction with peroxyl radicals.

In 2000, Nishiyama *et al.* [11] compared the peroxyl radical trapping ability of several phenols such as hydroxybenzofurans, hydroxychromanones and hydroxyl-xanthenes. The higher antioxidant activity than BHT was observed in 1,3,4,5,6,8-hexamethylxanthene-2,7-diols and 2-ethoxycarbonyl-5,6-dihydroxy-2,3-dihydro-benzofuran.

In 2003, Nenadis *et al*. [12] studied the differences in the antioxidant activity of ferulic acid derivatives induced by the presence of characteristic groups (-COOH, -CHO, -CH$_2$OH, -CH$_3$, and –COOC$_2$H$_5$) at the end of their carbon side chain. The effect of carbon side chain characteristics groups was determined. The relative order of the scavenging activity toward the DPPH radical derived from kinetic studies was isoeugenol ∼ coniferyl alcohol >> ferulic acid ∼ coniferyl aldehyde ∼ ethyl ferulate.

1.3 Testing of the oxidative stability

Fundamental knowledge of the oxidative properties of lubricants is necessary to predict the long-term thermal stability of these fluids, which is a critically important lubricant property. Oxidation properties evaluated experimentally are often used to predict actual lubricant service life at high temperature and other extreme applications.

There are numerous ways to measure the oxidative stability of oil: turbine oil oxidation stability test (TOST; DIN 5158, ASTM-D 943, ASTM-D 4310), rotary bomb test (RBOT; ASTM-D 2272), differential scanning calorimetry (DSC) and Indiana stirring oxidation test (IOST). The petroleum industry requires a testing with much harsher conditions. The RBOT is the recommended test because of the environment in which they are used [4, 13].

1.3.1 Rotating bomb oxidation test (RBOT; ASTM-D 2272) [14]

This test method utilizes an oxygen-pressured bomb to evaluate the oxidation stability of the oils in the presence of water and a copper catalyst coil at 150^oC and 620 kPa of oxygen pressure. Moreover, the bomb was rotated axially at 100 rpm at an angle of 30° from the horizontal. The number of minutes required to reach a specific drop in gage pressure of oxygen is the oxidation stability of the test sample.

According the mentions, products derived from petroleum, such as gasoline and lubricants, and petrochemical products, such as plastics, fibres and rubbers are susceptible to oxidation and can be further decomposed by auto-oxidation during the period between the production and final use. Especially in lubricants, when one of the main applications of using concerned about extreme condition, such as, high temperature, the oxidation rate is increased. Exception of the effect to life time, it leads to the formation of gum that marked to increase in viscosity and formation of organic acids that corrosive to parts of engine. Therefore, one of the most studied researches in recent years is concerned with the oxidative degradation of petroleum products such as studying the effect to the stability and improving of this method [15-21].

In this research, the main aim is to improve the oxidative stability of the lubricating oil utilizing synthetic antioxidant compounds as an additive. Due to the wide application in food, pharmaceutical and chemical industries, phenolic antioxidant is an attractive group for studying their activity and the effect to thermal stability of the lubricant. In addition, it is known that monophenols has less antioxidant property than polyphenols, therefore, 1,4-benzenediols or hydroquinones being *p*-hydroxyphenol derivatives, is selected for the present examination. *Ortho*-substituents are attractive to study the effect to their antioxidant activity [9, 10]. The synthesis of antioxidant agents was performed employing aldol condensation reaction [22]. There are various methods being developed to define structure-activity relationships (SARs). Among those methods developed to estimate the radical-scavenging activity, assay based on the scavenging of 1,1-diphenyl-2-picrylhydrazyl (DPPH) is the most popular one. Being simple and rapid, the assay was used to study preliminarily on antioxidant property of all synthesized compounds [24].

DPPH radical form   DPPH non-radical form
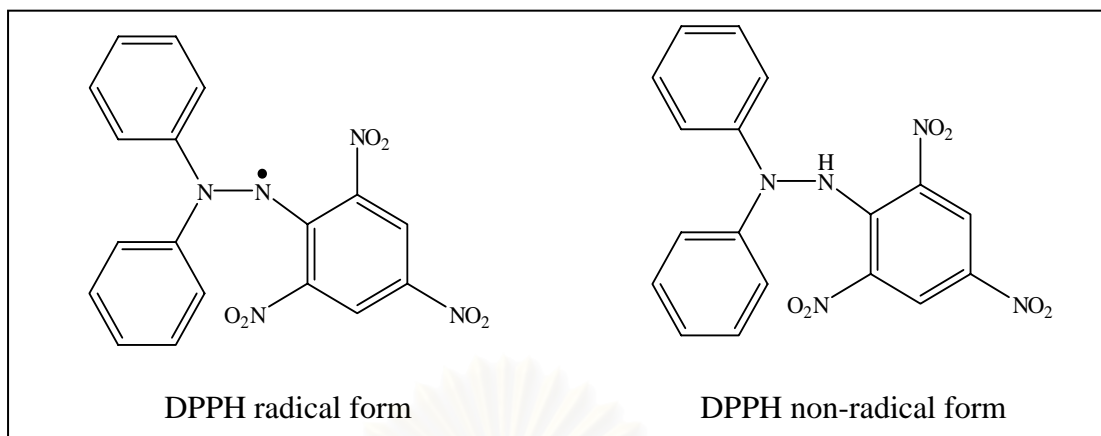
The effect of the synthetic 2-alkylated hydroquinones on the stability of lubricating oils was determined by standard test, rotary bomb oxidation test (ASTM-D 2272), using plain base oils. Thermal stability property of base oils can represent the antioxidant activity of these compounds.

1.4 The goal of this research

The attractive preliminary results for antioxidant activity of hydroquinones called for further intensive investigation. Therefore, the goal of this research can be summarized as:

1. To synthesize 2-alkylated hydroquinones and related compounds such as 2-alkylated-1,4-benzoquinone derivatives.
2. To preliminarily study on antioxidant property and to define structure-activity relationships (SARs) of these compounds.
3. To study the effect of these compounds on oxidative stability of lube base oil and to search for a new effective antioxidant for improving the oil having long life time.

CHAPTER II

EXPERIMENTAL

2.1 Instruments and Equipment

Melting points were measured on Fisher-Johns melting point apparatus and are uncorrected. Thin layer chromatography (TLC) was carried out on aluminium sheets precoated with silica gel (Merck's, Kieselgel 60 PF_{254}). Column chromatography was performed on silica gel (Merck's, Kieselgel 60 G). The FT-IR spectra were recorded on a Nicolet fourier transform infrared spectrophotometer model Impact 410. Solid samples were incorporated to potassium bromide to form pellet. The ^{1}H and ^{13}C NMR spectra were performed in deuterated chloroform, dimethylsulfoxide-d_6 or acetone-d_6 with tetramethylsilane as an internal reference on Bruker model ACF200 spectrometer and Varian model Mercury 400 and a Bruker FT-NMR spectrometer. The chemical shifts were assigned by comparison with residue solvent protons ($CDCl_3$/acetone-d_6 means that acetone-d_6 is added dropwise to a suspension of the compound in $CDCl_3$ until a clear solution is obtained).

DPPH scavenging tests were evaluated by HP 8543 UV-visible spectrophoto-meter. Oxidative stability of base oil samples were measured on Koehler K70490 Rotating Bomb Oxidation Tester at PTT Research and Technology Institute.

2.2 Chemicals

All solvents used in this research were purified by standard methodology except for those which were reagent grades. The reagents utilized for synthesizing 2-alkylated hydroquinones, 2-alkylated-1,4-benzoquinones and metal complexes were purchased from Fluka chemical company or otherwise stated and were used without further purification. 150SN typical lube base oil was obtained from PTT Public Company Limited. The oils were used without any further purification and processing.

2.3 Chemical Reactions

2.3.1 Synthesis of 2-alkylated hydroquinones [22]

2-Alkylated-hydroquinones were synthesized by mixing 1,4-cyclohexane dione 0.05 mol, aldehyde 0.05 mol and LiCl 0.05 mol in pyridine 20 mL. The mixture was allowed to reflux for 5-10 hours in an oil bath with stirring at atmospheric pressure. The reaction mixture was poured to 10% HCl and the product was extracted with EtOAc. The organic extract was washed with saturated solution of NaCl, dried over anhydrous Na_2SO_4 and evaporated. Purification of the residue was performed by silica gel column chromatography. All synthesized products are summarized as presented in Fig 2.1.
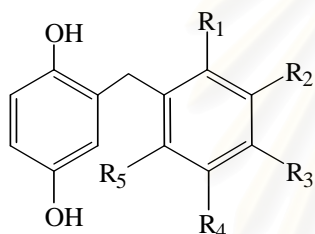
(H1) $R_1, R_2, R_3, R_4, R_5 = H$

(H2) $R_1 = OH, R_2, R_3, R_4, R_5 = H$

(H3) $R_1, R_3, R_4, R_5 = H, R_2 = OH$

(H4) $R_1, R_2, R_4, R_5 = H, R_3 = OH$

(H5) $R_1, R_3 = OH, R_2, R_4, R_5 = H$

(H6) $R_1, R_4, R_5 = H, R_2, R_3 = OH$

(H7) $R_1, R_2, R_3 = OH, R_4, R_5 = H$

(H8) $R_1, R_3, R_4, R_5 = H, R_2 = OCH_3$

(H9) $R_1, R_2, R_4, R_5 = H, R_3 = OCH_3$

(H10) $R_1, R_4, R_5 = H, R_2, R_3 = OCH_3$

(H11) $R_1, R_4, R_5 = H, R_2 = OCH_3, R_3 = OH$

(H12) $R_1, R_5 = H, R_2, R_4 = OCH_3, R_3 = OH$

(H13) $R_1, R_2, R_4, R_5 = H, R_3 = CH(CH_3)_2$
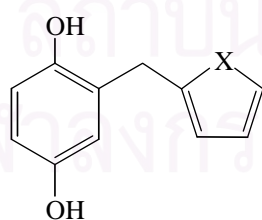
(H14) X = O

(H15) X = S
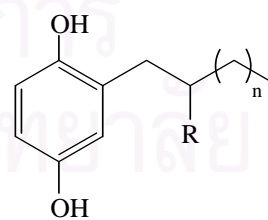
(H16) n = 1, R = C_2H_5

(H17) n = 6, R = H

(H18)

(H19) R = H

(H20) R = OH

(H21)
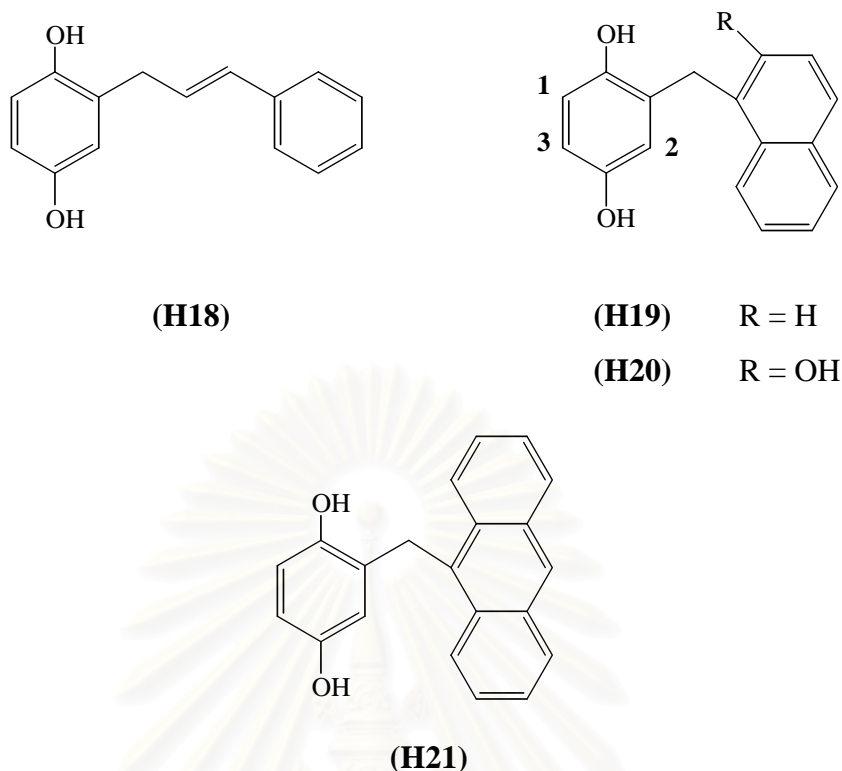
Figure 2.1 The structures of synthesized 2-alkylated hydroquinones

2-Benzyl hydroquinone (**H1**): dark purple solid (49% yield); m.p. 102-103 $^{\circ}$C; R_f 0.52 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3260 (br, O-H str), 3030 (m, C-H str of aromatic) and 1602, 1509 (w, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 8.65, 8.53 (s, 1H each, O-**H**), 7.11-7.30 (m, 5H, aromatic protons), 6.40-6.60 (m, 3H, aromatic protons) and 3.78 (s, 2H, -C**H**$_2$-).

2-(2-Hydroxybenzyl) hydroquinone (**H2**): light brown solid (21% yield); m.p. 137-138 $^{\circ}$C; R_f 0.51 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3280 (br, O-H str), 3023 (w, C-H str of aromatic) and 1622, 1579 (m, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 9.15 (s, O-**H**), 6.50-7.25 (m, 7H, aromatic protons) and 3.95 (s, 2H, -C**H**$_2$-).

2-(3-Hydroxybenzyl) hydroquinone (**H3**): light brown solid (30% yield); m.p. 135-136 $^{\circ}$C; R_f 0.26 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3358 (br, O-H str), 2925 (w, C-H str of aromatic), 1587, 1497 (s, C=C str of aromatic) and 1156 (s, C-O str); ^{1}H-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 9.19, 8.63, 8.53 (s, 1H each, O-**H**), 6.34-7.00 (m, 7H, aromatic protons) and 3.64 (s, 2H, -C**H**$_2$-); ^{13}C-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 112.6-157.2 (12C, aromatic carbons) and 35.1 (1C, -C**H**$_2$-).

2-(4-Hydroxybenzyl) hydroquinone **(H4):** brown solid (58% yield); m.p. 128-129 $^{\circ}$C; R_f 0.31 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3346 (br, O-H str), 3058 (w, C-H str of aromatic) and 1629, 1602 (m, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 9.11, 8.59, 8.50 (s, 1H each, O-**H**), 6.98-6.38 (m, 7H, aromatic protons) and 3.66 (s, 2H, -C**H**$_2$-).

2-(2,4-Dihydroxybenzyl) hydroquinone **(H5):** dark red solid (31% yield); m.p. 182-183 $^{\circ}$C; R_f 0.35 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3264 (br, O-H str), 3034 (m, C-H str of aromatic) and 1620, 1501 (s, C=C str of aromatic); ^{1}H-NMR (400 MHz, DMSO-d$_6$) δ (ppm): 9.44, 9.16 (s, O-**H**), 6.37-6.98 (m, 6H, aromatic protons) and 3.81 (s, 2H, -C**H**$_2$-).

2-(3,4-Dihydroxybenzyl) hydroquinone **(H6):** light orange solid (31% yield); m.p. 164-165 $^{\circ}$C; R_f 0.22 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3299 (br, O-H str), 2914 (w, C-H str of aromatic), 1610, 1505 (s, C=C str of aromatic) and 1193 (s, C-O str); ^{1}H-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 8.58 (s, 4H, O-**H**), 6.31-6.64 (m, 6H, aromatic protons) and 3.81 (s, 2H, -C**H**$_2$-); ^{13}C-NMR (200 MHz, DMSO-d$_6$) δ (ppm): 112.9-149.6 (12C, aromatic carbons) and 34.6 (1C, -C**H**$_2$-).

2-(2,3,4-Trihydroxybenzyl) hydroquinone **(H7):** dark purple solid (21% yield); m.p. 166-169 $^{\circ}$C; R_f 0.30 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3369 (br, O-H str), 2965 (w, C-H str of aromatic), 1699, 1633 (s, C=C str of aromatic) and 1214 (s, C-O str); ^{1}H-NMR (400 MHz, DMSO-d$_6$) δ (ppm): 9.12, 8.91, 8.49 (s, O-**H**), 6.89 (d, 1H, J = 8.80 Hz, aromatic proton), 6.46-6.94 (m, 5H, aromatic protons) and 3.81 (s, 2H, -C**H**$_2$-). ^{13}C-NMR (400 MHz, DMSO-d$_6$) δ (ppm): 110.5-153.2 (12C, aromatic carbons) and 27.5 (1C, -C**H**$_2$-).

2-(3-Methoxybenzyl) hydroquinone **(H8):** brown solid (40% yield); m.p. 176-177 $^{\circ}$C; R_f 0.45 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3382 (br, O-H str), 3021 (w, C-H str of aromatic), 1611, 1584 (m, C=C str of aromatic) and 1142 (s, C-O str); ^{1}H-NMR (400 MHz, acetone-d$_6$, CDCl$_3$) δ (ppm): 6.51-7.14 (m, 7H, aromatic protons), 3.87 (s, 2H, -C**H**$_2$-) and 3.71 (s, 3H, -OC**H**$_3$). ^{13}C-NMR (400 MHz, acetone-d$_6$, CDCl$_3$) δ (ppm): 110.8-159.7 (12C, aromatic carbons), 54.6 (1C, -O**C**H$_3$) and 35.6 (1C, -**C**H$_2$-).

2-(4-Methoxybenzyl) hydroquinone **(H9):** light brown solid (41% yield); m.p. 128-129 $^{\circ}$C; R_f 0.22 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3385 (br, O-H str), 3027 (w, C-H str of aromatic) and 1610, 1513 (s, C=C str of aromatic); ^{1}H-NMR (200 MHz,

DMSO-d_6) δ (ppm): 8.66, 8.56 (s, 1H each, O-**H**), 7.11 (d, 2H, J = 8.58 Hz, aromatic protons), 6.81 (d, 2H, J = 8.58 Hz, aromatic protons), 6.32-6.61 (m, 3H, aromatic protons), 3.70 (s, 3H, -OC**H**$_3$) and 3.69 (s, 2H, -C**H**$_2$-).

2-(3,4-Dimethoxybenzyl) hydroquinone (H10): dark orange solid (21% yield); m.p. 146-147 ^{o}C; R_f 0.40 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3357 (br, O-H str), 3065 (w, C-H str of aromatic) and 1587, 1516 (s, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d_6) δ (ppm): 8.52, 8.64 (s, O-**H**), 6.34-6.86 (m, 6H, aromatic protons) and 3.70 (s, 8H, 2xOC**H**$_3$, -C**H**$_2$-).

2-(4-Hydroxy-3-methoxybenzyl) hydroquinone (H11): light brown solid (69% yield); m.p. 178-179 ^{o}C; R_f 0.28 (EtOAc:hexane 1:1); IR (KBr, cm^{-1}): 3308 (br, O-H str), 2995 (w, C-H str of aromatic), 1603, 1505 (m, C=C str of aromatic) and 1186 (s, C-O str); ^{1}H-NMR (400 MHz, DMSO-d_6) δ (ppm): 8.71, 8.64, 8.53 (s, 1H each, O-**H**), 6.80-6.37 (m, 6H, aromatic protons), 3.73 (s, 3H, -OC**H**$_3$) and 3.68 (s, 2H, -C**H**$_2$-); ^{13}C-NMR (400 MHz, acetone-d_6, CDCl$_3$) δ (ppm): 117.7-155.1 (12C, aromatic carbons), 60.4 (1C, -OC**H**$_3$) and 40.2 (1C, -C**H**$_2$-).

2-(4-Hydroxy-3,5-methoxybenzyl) hydroquinone (H12): dark brown solid (22% yield) was obtained; m.p. 176-177 ^{o}C; R_f 0.36 (EtOAc:hexane 7:3); IR (KBr, cm^{-1}): 3357 (br, O-H str), 2943 (w, C-H str of aromatic), 1614, 1522 (m, C=C str of aromatic) and 1114 (s, C-O str); ^{1}H-NMR (400 MHz, DMSO-d_6) δ (ppm): 8.66, 8.52, 8.11 (s, 1H each, O-**H**), 6.38-6.62 (m, 5H, aromatic protons), 3.72 (s, 6H, 2x-OC**H**$_3$) and 3.68 (s, 2H, -C**H**$_2$-); ^{13}C-NMR (400 MHz, DMSO-d_6) δ (ppm): 106.9-150.1 (12C, aromatic carbons), 56.4 (2C, 2xOC**H**$_3$) and 35.6 (1C, -C**H**$_2$-).

2-(4-Isopropylbenzyl) hydroquinone (H13): brown solid (52% yield); m.p. 109-110 ^{o}C; R_f 0.29 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3302 (br, O-H str), 2960 (w, C-H str of aromatic), 1603, 1511 (m, C=C str of aromatic) and 1193 (s, C-O str.); ^{1}H-NMR (400 MHz, DMSO-d_6) δ (ppm): 8.66, 8.56 (s, 1H each, O-**H**), 6.41-7.13 (m, 7H, aromatic protons), 3.75 (s, 2H, -C**H**$_2$-), 2.84 (hept, 1H, J = 6.80 Hz, -C**H**-) and 1.18 (d, 6H, J = 6.80 Hz, 2x-C**H**$_3$); ^{13}C-NMR (400 MHz, acetone-d_6, CDCl$_3$) δ (ppm): 113.4-150.1 (12C, aromatic carbons), 35.3 (1C, -C**H**-(CH$_3$)$_2$), 33.6 (1C, Ar-C**H**$_2$-Ar) and 23.8 (2C, 2x-C**H**$_3$).

2-(2-Methylfuranyl) hydroquinone (H14): brown solid (37% yield); m.p. 47-48 ^{o}C; R_f 0.31 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3346 (br, O-H str), 3034 (m, C-H str of aromatic) and 1606, 1513 (s, C=C str of aromatic); ^{1}H-NMR (400 MHz,

DMSO-d_6) δ (ppm): 8.73, 8.62 (s, 1H each, O-**H**), 6.03-7.49 (m, 6H, aromatic protons) and 3.79 (s, 2H, -C**H**$_2$-).

2-(2-Methylthiophenyl) hydroquinone (**H15**): dark brown solid (35% yield); m.p. 92-93 ^{o}C; R_f 0.35 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3182 (br, O-H str) and 1594, 1493 (m, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d_6) δ (ppm): 8.76, 8.62 (s, 1H each, O-**H**), 6.41-7.28 (m, 6H, aromatic protons) and 3.97 (s, 2H, -C**H**$_2$-).

2-(2-Ethylbutyl) hydroquinone (**H16**): light brown solid (26% yield); m.p. 106-107 ^{o}C; R_f 0.45 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3342 (br, O-H str), 3034 (w, C-H str of aromatic), 2953, 2859 (m, C-H str of CH$_2$ and CH$_3$), 1707, 1602 (m, C=C str of aromatic) and 1190 (s, C-O str.); ^{1}H-NMR (400 MHz, DMSO-d_6) δ (ppm): 8.45, 8.40 (s, 1H each, O-**H**), 6.35-6.54 (m, 3H, aromatic protons), 2.35 (d, 2H, $J = 7.20$ Hz, Ar-C**H**$_2$-), 1.46-1.49 (m, 1H, Ar-CH$_2$-C**H**-), 1.21 (quin, 4H, $J = 6.00$ Hz, 2x-C**H**$_2$-CH$_3$) and 0.78-0.82 (t, 6H, $J = 7.20$ Hz, 2x-C**H**$_3$); ^{13}C-NMR (400 MHz, DMSO) δ (ppm): 113.2-149.9 (6C, aromatic carbons), 40.8 (1C, Ar-CH$_2$-**C**H-), 34.1 (1C, Ar-**C**H$_2$-), 25.1 (2C, 2x-**C**H$_2$-CH$_3$) and 11.1 (2C, 2x-**C**H$_3$).

2-Octyl hydroquinone (**H17**): light brown solid (28% yield); m.p. 95-96 ^{o}C; R_f 0.40 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3259 (br, O-H str) and 1618 (w, C=C str of aromatic); ^{1}H-NMR (200 MHz, DMSO-d_6) δ (ppm): 8.50, 8.43 (s, O-**H**), 6.31-6.61 (m, 3H, aromatic protons), 2.15-2.52 (m, 2H, -C**H**$_2$-Ar), 1.24-1.47 (m, 12H, -C**H**$_2$-) and 0.82-0.88 (m, 3H, -C**H**$_3$).

2-(3-Phenylallyl) hydroquinone (**H18**): dark orange solid (26% yield); m.p. 102-104 ^{o}C; R_f 0.48 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3244 (br, O-H str), 3023 (w, C-H str of aromatic) and 1598, 1497 (m, C=C str of aromatic); ^{1}H-NMR (400 MHz, DMSO-d_6) δ (ppm): 8.72, 8.65 (s, 1H each, O-**H**), 7.19-7.40 (m, 5H, aromatic protons), 6.29-6.63 (m, 5H, aromatic and alkene protons) and 3.37 (d, 2H, $J = 5.40$ Hz, -C**H**$_2$-CH=CH-).

2-(1-Methylnaphthalenyl) hydroquinone (**H19**): light red solid (74% yield); m.p. 145-147 ^{o}C; R_f 0.45 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3293 (br, O-H str), 3048 (w, C-H str of aromatic) and 1615 (w, C=C str of aromatic); ^{1}H-NMR (400 MHz, acetone-d_6) δ (ppm): 7.31-8.06 (m, 7H, naphthenic protons), 6.74 (d, 1H, $J = 8.53$ Hz, **H(1)**), 6.50-6.53 (dd, 1H, $J = 2.80, 6.50$ Hz, **H(2)**), 6.27 (d, 1H, $J = 2.81$ Hz, **H(3)**) and 4.36 (s, 2H, -C**H**$_2$-).

***2-(2-Hydroxy-1-methylnaphthalenyl) hydroquinone* (H20):** dark orange solid (57% yield); m.p. 157-158 ^{o}C; R_f 0.44 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3337 (br, O-H str), 3055 (w, C-H str of aromatic), 1616, 1507 (m, C=C str of aromatic) and 1218 (s, C-O str.); ^{1}H-NMR (400 MHz, DMSO-d$_6$) δ (ppm): 9.31 (s, O-**H**), 6.67-7.96 (m, 9H, aromatic protons) and 4.33 (s, 2H, -**CH**$_2$-); ^{13}C-NMR (400 MHz, DMSO) δ (ppm): 111.5-153.7 (16C, aromatic carbons) and 24.7 (1C, -**CH**$_2$-).

***2-(9-Methylantracenyl) hydroquinone* (H21):** light yellow solid (62% yield); m.p. 190-192 ^{o}C; R_f 0.75 (EtOAc:hexane 3:7); IR (KBr, cm^{-1}): 3246 (br, O-H str), 3048 (w, C-H str of aromatic) and 1619 (w, C=C str of aromatic); ^{1}H-NMR (400 MHz, acetone-d$_6$) δ (ppm): 8.57 (s, 1H, anthracenic proton), 7.53-8.32 (m, 8H, anthracenic protons), 6.84 (d, 1H, J = 8.56 Hz, **H(3)**), 6.47-6.50 (dd, 1H, J = 6.50, 2.80 Hz, **H(1)**), 5.84 (d, 1H, J = 2.75 Hz, **H(2)**) and 4.96 (s, 2H, -**CH**$_2$-).

### 2.3.2   Synthesis of 2-alkylated-1,4-benzoquinones [25]

2-Alkylated-1,4-benzoquinones were achieved by aerobic oxidation of 2-alkylated hydroquinones 1 mmol utilizing cobalt(II)salen (Co-salen) 0.1 mmol as a catalyst in DMF 10 mL at room temperature under O$_2$ atmosphere. After 5-10 hours, the reaction mixture was added to 10% H$_2$SO$_4$ and then extracted with diethyl ether. The organic layer was washed with saturated solution of NaHCO$_3$, dried and evaporated. Silica gel column chromatography was used to purify the benzoquinone products.

Preparation of Co(salen) catalyst [**25**]
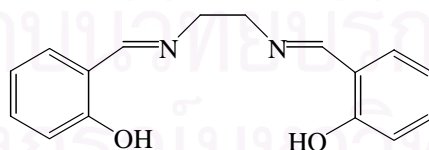
Salen or bis(salicylaldehyde)*N,N′*-ethylenediimine, ligand of cobalt complex catalyst was prepared by slowly adding ethylenediamine (0.06 mol) to salicylaldehyde (0.15 mol) at room temperature. The yellow precipitate occurred immediately, filtered and recrystallized by 95% EtOH yielding 96% yield of bright yellow plates; m.p. 124-125 ^{o}C; R_f 0.74 (CH$_2$Cl$_2$); IR (KBr, cm^{-1}): 3500 (w), 3010-3050 (w), 2870-2950 (w), 1750-2000 (w), 1640 (s), 1450-1600 (s), 1280 (s) and 1170 (s); ^{1}H-NMR (CDCl$_3$) δ

(ppm): 3.84 (s, 4H), 6.83 (dt, J = 7.48, 1.22 Hz, 2H), 6.93 (d, J = 8.24 Hz, 2H), 7.18 (dd, J = 7.78, 1.53 Hz, 2H), 7.26 (dt, J = 7.78, 1.53 Hz, 2H), 8.29 (s, 2H) and 13.2 (s, 2H); ^{13}C-NMR (CDCl$_3$) δ (ppm): 59.5 (2C), 116.8 (2C), 118.5 (4C), 131.4 (2C), 132.2 (2C), 160.9 (2C) and 166.3 (2C).
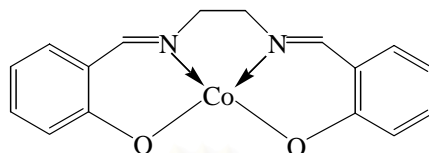
Cobalt (II) salen complex was synthesized by dissolving salen (0.01 mol) in 50 mL ethanol at 70 $^{\circ}$C. Until the solution homogeneity, Co(II) acetate tetrahydrate (0.01 mol) in 25 mL ethanol was dropped slowly and then refluxed for 1 hr. Precipitate of Co(salen) had occurred. The products were filtered and washed with cold ethanol. The red solid was obtained in 68% yield; m.p. 228.5 $^{\circ}$C; IR (KBr, cm^{-1}): 3500 (br, O-H str), 3020 (w, C-H str of aromatic), 2900 (w, C-H str of aliphatic) and 1640 (m, C=N str).

The structures of all synthesized 2-alkylated-1,4-benzoquinones are presented as shown in Fig 2.2.
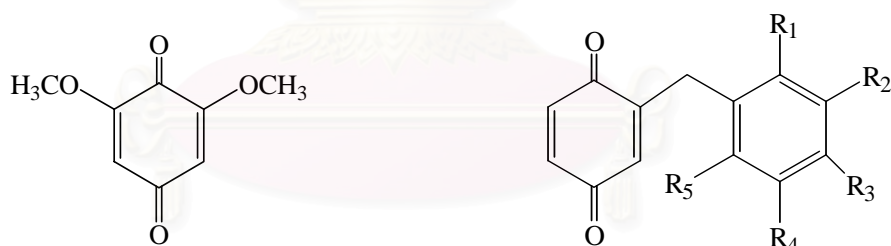
(Q1)   (Q2) R_1, R_2, R_3, R_4, R_5 = H

(Q3) R_1, R_3, R_4, R_5 = H, R_2 = OH

(Q4) R_1, R_2, R_4, R_5 = H, R_3 = OCH$_3$

Figure 2.2 The structures of synthesized 2-alkylated-1,4-benzoquinones

2,6-Dimethoxy-1,4-benzoquinone (**Q1**): yellow crystal (54% yield); R_f 0.20 (CH$_2$Cl$_2$); IR (NaCl, cm^{-1}): 3062 (w, C-H str of olefinic), 1696 (m, C=O str) and 1645, 1590 (m, C=C str of olefinic); ^{1}H-NMR (400 MHz, CDCl$_3$) δ (ppm): 5.89 (s, 2H, olefinic protons) and 3.86 (s, 6H, 2x-OC**H**$_3$).

2-Benzyl-1,4-benzoquinone **(Q2):** brown liquid (54% yield); R_f 0.54 (hexane : CH_2Cl_2 1:1); IR (NaCl, cm^{-1}): 3057 (w, C-H str of aromatic), 1657 (m, C=O str) and 1598 (w, C=C str of aromatic); ^{1}H-NMR (400 MHz, $CDCl_3$) δ (ppm): 6.40-7.38 (m, 8H, olefinic and aromatic protons) and 3.78 (s, 2H, -**CH**$_2$).

2-(3-Hydroxybenzyl)-1,4-benzoquinone **(Q3):** dark red solid (56% yield); R_f 0.66 (CH_2Cl_2); IR (KBr, cm^{-1}): 3252 (br, O-H str), 3058 (w, C-H str of aromatic), 1645 (s, C=O str) and 1583, 1485 (m, C=C str of aromatic); ^{1}H-NMR (400 MHz, $CDCl_3$) δ (ppm): 7.23 (t, 1H, J = 7.83 Hz, aromatic proton), 6.71-6.83 (m, 5H, olefinic and aromatic protons), 6.44 (s, 1H, aromatic proton) and 3.73 (s, 2H, -**CH**$_2$); ^{13}C-NMR (400 MHz, DMSO) δ (ppm): 193.1, 192.6 (2C, carbonyl carbons), 162.4-118.9 (10C, aromatic and olefinic carbons) and 39.8 (1H, -**CH**$_2$-)

2-(4-Methoxybenzyl)-1,4-benzoquinone **(Q4):** brown liquid (81% yield); R_f 0.80 (CH_2Cl_2); IR (NaCl, cm^{-1}): 3003 (w, C-H str of aromatic), 1653 (m, C=O str) and 1606, 1509 (m, C=C str of aromatic); ^{1}H-NMR (400 MHz, $CDCl_3$) δ (ppm): 7.14 (d, 2H, J = 8.58 Hz, aromatic protons), 6.89 (d, 2H, J = 8.58 Hz, aromatic protons), 6.39-6.52 (m, 3H, olefinic protons), 3.83 (s, 3H, -O**CH**$_3$) and 3.72 (s, 2H, -**CH**$_2$).

2.4 Solubility Test [26]

0.10 g of solid or 0.20 mL of liquid samples was observed its solubility in 3.0 mL of solvent. The samples are carried out in a small test-tube at room temperature (30°C). The solvents were dropped slowly to the sample and shake vigorously until the homogeneous solution was obtained. If the sample does not dissolve, the mixture will be heated in water bath. The solvents employed in the solubility test included acetone, CH_2Cl_2, EtOAc, water, methanol, isooctane, THF, DMF, diethyl ether, hexane, EtOH and toluene.

2.5 Preliminary study of antioxidant activity

Scavenging effects on DPPH radicals [24]

2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical is a stable radical with a purple color (λ_{max} 517 nm). Upon reduction by a scavenger, the extensive conjugation is disrupted and the compound turns yellow.

2.5.1 TLC autographic assay

After developing and drying, TLC plates were sprayed with a 0.2% DPPH in methanolic solution. The plates were examined for 5 minutes after spraying. Active compounds would appear as yellow spots against purple background.

2.5.2 Spectrophotometric assay

Samples of various concentrations (0.5 mL) were added to a 1 mL methanolic solution of DPPH radical (final concentration of DPPH was 0.2 mM). The mixture was shaken vigorously and then left for 30 minutes. The absorbance of the resulting solution was measured at 517 nm with a spectrophotometer. All tests and analyses were run in three replicates and averaged. Calculate the percentage of radical scavenging by the following equation.

$$\text{The percentage of radical scavenging } = (1 - A_{sample}/A_{control}) \times 100$$

A_{sample} = Absorbance of sample solution with DPPH

$A_{control}$ = Absorbance of only DPPH and used solvent

2.6 Laurylation reaction of 2-alkylated hydroquinones [27]

Alkylation reaction was performed by adding the synthesized 2-alkylated hydroquinones (3.75 mmol) and *n*-lauryl alcohol (0.7 g) to 85% phosphoric acid (0.21 g) in 3 mL of toluene. The reaction mixture was refluxed for 6.5 h. After that, the mixture was extracted with dichloromethane and washed with saturated solution of NaHCO$_3$ and NaCl. The crude product was purified by column chromatography. The structures of synthesized products are presented in Fig 2.3.
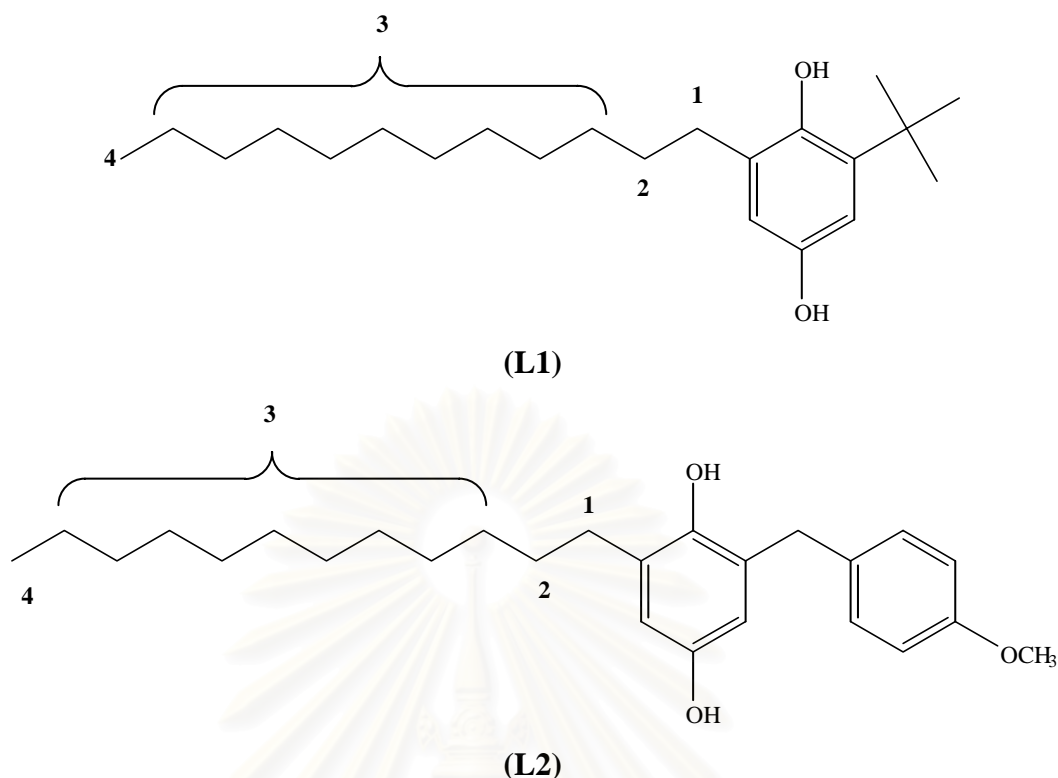
Figure 2.3 The structures of 2-alkylated-6-lauryl hydroquinones

2-tert-Butylated-6-lauryl hydroquinone (**LTBHQ, L1**): yellow liquid (11% yield); R_f 0.66 (hexane:CH_2Cl_2 1:1); IR (NaCl, cm^{-1}): 3404 (br, O-H str), 2925 (w, C-H str of aromatic) and 1583, 1509 (C=C str of aromatic); ^{1}H-NMR (400 MHz, CDCl$_3$) δ (ppm): 6.62-6.63 (m, 2H, aromatic protons), 4.55 (s, O-**H**), 3.92 (t, 2H, *J* = 6.59 Hz, **H(1)**), 1.77-1.82 (quin, 2H, *J* = 6.80 Hz, **H(2)**), 1.30-1.49 (m, 27H, **H(3)** and *tert*-bultylated protons) and 0.92 (m, 3H, **H(4)**).

2-(4-methoxybenzyl)-6-lauryl hydroquinone (**L2**): white solid (trace); R_f 0.58 (CH$_2$Cl$_2$); IR (KBr, cm^{-1}) 3385 (br, O-H str), 2918 (m, C-H str of aromic), 1601, 1513 (C=C str of aromatic); ^{1}H-NMR (400 MHz, CDCl$_3$) δ (ppm): 7.18 (d, 2H, *J* = 8.45 Hz, aromatic protons), 6.87 (d, 2H, *J* = 8.54 Hz, aromatic protons), 6.71-6.74 (m, 2H, aromatic protons), 4.38 (s, O-**H**), 3.88-3.93 (m, 4H, **H(1)** and –**CH₂-**), 3.82 (s, 3H, -O**CH₃**), 1.73-1.80 (quin, 2H, *J* = 6.94 Hz, **H(2)**), 1.30-1.33 (m, 18H, **H(3)**) and 0.91 (m, 3H, **H(4)**)); ^{13}C-NMR (400 MHz, CDCl$_3$) δ (ppm): 158.2-113.1 (12C, aromatic carbons), 55.6 (1C, -O**CH₃**), 35.9 (1C, -**CH₂**-) and 14.2-32.2 (12C, long chain carbons).

2.7 Oxidative stability of lubricants by RBOT [14]

Following ASTM D2272 procedure, 50 ± 0.5 g of lube base oil and 5 mL of water were added into glass sample container which contained copper catalyst coil. Having been covered with PTFE (polytetrafluoroethylene) disk, the container was slide to the bomb body, which contained 5 mL of water, and cover lid into the body. The bomb cap was inserted into the bomb body with silicone stopcock grease as lubricator. Then, the gage was screwed into the bomb stem. The oxygen gas was flushed to the bomb three times before the bomb was replaced in constant-temperature oil bath at 150°C and rotated at 100 ± 5 rpm. The test is complete after the pressure drops more than 175 kPa (25.4 psi) below the maximum pressure, which called break point. Induction period, the time elapsed between the placing of the pressure vessel in the bath and the break point at 150°C, is shown as an indication for lube base oil stability.

CHAPTER III

RESULTS AND DISCUSSION

This research was mainly focused on the synthesis and evaluation of antioxidant property of hydroquinone derivatives and related compounds in order to search for a new efficient antioxidant employing in lubricating oil. DPPH assay was used as a viable method to preliminarily screen for their antioxidant activity [24]. High potent compounds were then explored utilizing delaying lifetime procedure in base oil by rotary bomb method [14].

3.1 Synthesis and characterization

3.1.1   2-Alkylated hydroquinones

A series of 2-alkylated hydroquinones (or 2-alkylated-1,4-benzenediols) was fruitfully synthesized employing aldol condensation between 1,4-cyclohexane-dione and varieties of aldehydes in the presence of LiCl and pyridine as catalyst and solvent, respectively [22] as shown below. The products were purified by column chromatograph using hexane-EtOAc as solvent system.
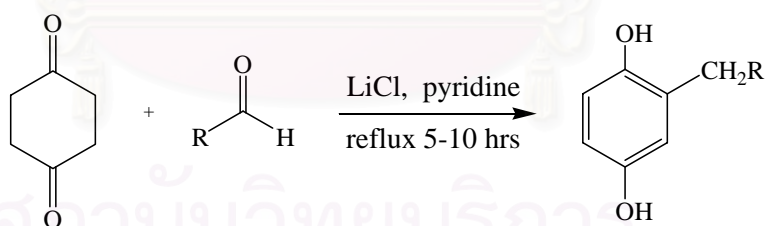
Twenty-one 2-alkylated hydroquinones were accomplishly synthesized as presented their structures in Figure 2.1. Considering based upon the substitutent at *ortho* position, four groups including benzyl group (**H1**-**H13**), substituent containing heterocyclic group (**H14**-**H15**), long alkyl chain group (**H16**-**H18**) and polyaromatic group (**H19**-**H21**) were achieved. Among them, nine compounds (structures depicted below) namely 2-(3-hydroxybenzyl) hydroquinone **(H3)**, 2-(3,4-dihydroxybenzyl) hydroquinone **(H6)**, 2-(2,3,4-trihydroxybenzyl) hydroquinone **(H7)**, 2-(3,4-dihydroxy

benzyl) hydroquinone **(H8)**, 2-(4-hydroxy-3-methoxy benzyl) hydroquinone **(H11)**, 2-(4-hydroxy-3,5-methoxybenzyl) hydroquinone **(H12)**, 2-(4-isopropylbenzyl) hydro-quinone **(H13)**, 2-(2-ethylbutyl) hydroquinone **(H16)** and 2-(2-hydroxy-1-methyl naphthalenyl) hydroquinone **(H20)** were disclosed to be new compounds based upon no report addressed in chemical literature.
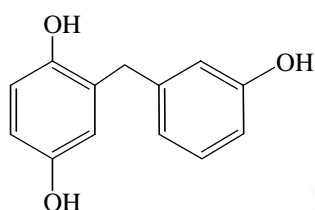
H3
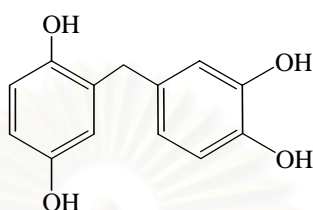
H6

H7

H8

H11

H12

H13

H16

H20
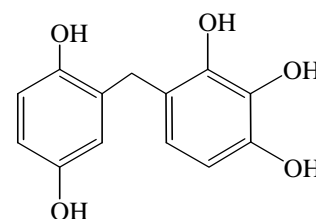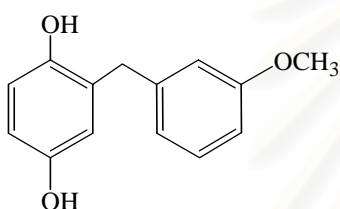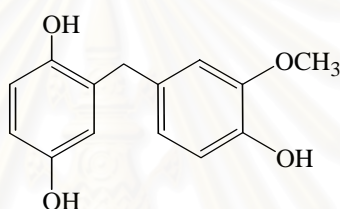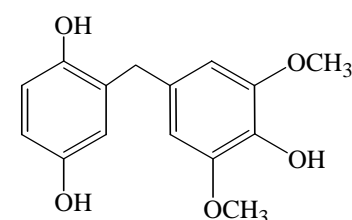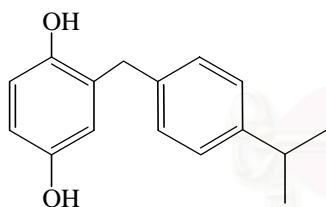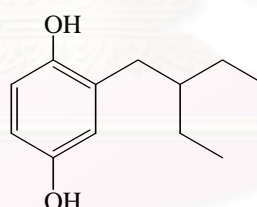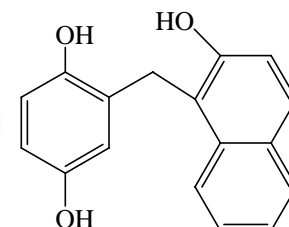
3.1.2 Spectroscopy of 2-alkylated hydroquinones

All synthesized 2-alkylated hydroquinones were confirmed their identities by spectroscopic data including IR and ^{1}H-NMR. Especially, new hydroquinones were additionally characterized by ^{13}C-NMR. The spectra of nine new compounds are demonstrated in Appendix A (Figures A.1-A.27).

Infrared spectroscopy (IR)

The IR absorption pattern for all synthesized 2-alkylated hydroquinones showed the common characteristics of their functional group. To illustrate this, the O-H stretching vibration of hydroxyl group around 3300 cm^{-1}, that of C-H stretching of aromatic moiety around 3050-2900 cm^{-1} and that of C=C ring stretching around 1600, 1500 cm^{-1} were observed. The FT-IR absorption band assignments of new synthetic 2-alkylated-hydroquinones are tabulated in Table 3.1.

Table 3.1 The IR absorption band assignments of new synthesized 2-alkylated-hydroquinones

Compound	Wave number (cm^{-1})			
	O-H str.	C-H str.	C=C str. (aromatic)	C-O str.
H3	3358 (br)	2925 (w)	1587, 1497 (s)	1156 (s)
H6	3299 (br)	2941 (w)	1610, 1505 (m)	1193 (s)
H7	3369 (br)	2965 (w)	1699, 1633 (m)	1214 (s)
H8	3382 (br)	3021 (w)	1611, 1584 (m)	1142 (s)
H11	3308 (br)	2995 (w)	1603, 1505 (m)	1186 (s)
H12	3357 (br)	2943 (w)	1614, 1522 (m)	1114 (s)
H13	3302 (br)	2960 (w)	1603, 1511 (m)	1193 (s)
H16	3342 (br)	3034 (w)	1707, 1602 (m)	1190 (s)
H20	3337 (br)	3055 (w)	1616, 1507 (m)	1218 (s)

Nuclear magnetic resonance spectroscopy (NMR)

^{1}H-NMR

The ^{1}H-NMR spectra of synthesized 2-alkylated hydroquinones generally display the proton signals as follows: protons of hydroxyl group around δ 8.7, aromatic protons approximately at δ 6.0-7.0 and protons of methylene and methoxy groups around δ 3.7-3.8. The ^{1}H-NMR chemical shift assignments of all new compounds were tentatively assigned as presented in Tables 3.2 and 3.4.

^{13}C-NMR

The ^{13}C-NMR spectra of synthesized 2-alkylated hydroquinones show important signals of aromatic carbons in the range of δ 110-160, carbons of methoxy group around δ 55 and methylene carbons approximately at δ 30. The chemical shifts of all new compounds were also assigned as shown in Tables 3.3 and 3.4.

Table 3.2 The ^{1}H chemical shift assignments of **H3**, **H6**, **H7**, **H8**, **H9**, **H11**, **H12** and **H13**

Compounds	Chemical shift (ppm)										
	-OH	**H^a**	**H^b**	**H^c**	**H^d**	**H^e**	**H^f**	**H^g**	**H^h**	**-CH$_2$-**	**substituent**
H3	9.19, 8.63, 8.53 (s, 1H each)	6.34-6.68 (m, 4H)				-	6.34-6.68 (m, 1H)	7.03 (t, 1H, *J*=7.6)	6.34-6.68 (m, 1H)	3.64 (s, 2H)	-
H6	8.58 (br, 4H)	6.31-6.64 (m,4H)				-	-	6.31-6.64 (m, 2H)		3.81 (s, 2H)	-
H7	9.12, 8.91, 8.50 (s, 5H)	6.89 (d, 1H, *J*=8.8)	6.44-6.59 (m, 2H)		-	-	-	6.44-6.59 (m, 2H)		3.79 (s, 2H)	-
H8	-*	6.66 (d, 1H, *J*=8.4)	6.51-6.59 (m, 2H)		6.75-6.83 (m, 1H)	-	6.75-6.83 (m, 1H)	7.08-7.14 (m, 1H)	6.75-6.83 (m, 1H)	3.87 (s, 2H)	3.71 (s, 3H, OCH$_3$)
H11	8.71, 8.64, 8.53 (s, 1H each)	6.67 (d, 1H, *J*=8.0)	6.37-6.41 (m, 2H)		6.57-6.61 (m, 1H)	-	-	6.90 (d, 1H, *J*=8.0)	6.57-6.61 (m, 1H)	3.68 (s, 2H)	3.73 (s, 3H, OCH$_3$)
H12	8.66, 8.52, 8.11 (s, 1H each)	6.61 (d, 1H, *J*=8.0)	6.38-6.42 (m, 2H)		6.49 (s, 1H)	-	-	-	6.49 (s,1H)	3.68 (s, 2H)	3.72 (s, 6H, OCH$_3$)
H13	8.66, 8.56 (s, 1H each)	6.61 (d, 1H, *J*=8.8)	6.41-6.42 (m, 2H)		7.13 (s, 2H)	-	7.13 (s, 2H)			3.75 (s, 2H)	2.84 (hept,1H, *J*=6.8,-C**H**-), 1.18 (d, 6H, *J*=6.8,-C**H$_3$**)

*not detected
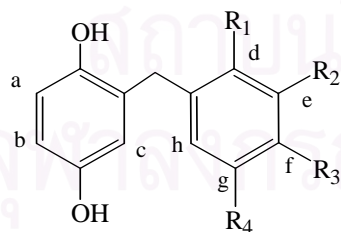
H3: R$_1$, R$_3$, R$_4$ = H, R$_2$ = OH
H6: R$_1$, R$_4$ = H, R$_2$, R$_3$ = OH
H7: R$_1$, R$_2$, R$_3$ = OH, R$_4$ = H
H8: R$_1$, R$_3$, R$_4$ = H, R$_2$ = OCH$_3$
H11: R$_1$, R$_4$ = H, R$_2$ = OCH$_3$, R$_3$ = OH
H12: R$_1$ = H, R$_2$, R$_4$ = OCH$_3$, R$_3$ = OH
H13: R$_1$, R$_2$, R$_4$ = H, R$_3$ = *i*-pr

Table 3.3 The ^{13}C chemical shift assignments of **H3**, **H6**, **H7**, **H8**, **H9**, **H11**, **H12** and **H13**
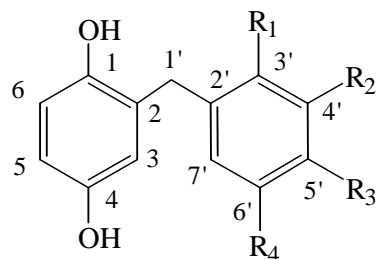
H3: R$_1$, R$_3$, R$_4$ = H, R$_2$ = OH
H6: R$_1$, R$_4$ = H, R$_2$, R$_3$ = OH
H7: R$_1$, R$_2$, R$_3$ = OH, R$_4$ = H
H8: R$_1$, R$_3$, R$_4$ = H, R$_2$ = OCH$_3$
H11: R$_1$, R$_4$ = H, R$_2$ = OCH$_3$, R$_3$ = OH
H12: R$_1$ = H, R$_2$, R$_4$ = OCH$_3$, R$_3$ = OH
H13: R$_1$, R$_2$, R$_4$ = H, R$_3$ = *i*-pr

Compound	Position													
	1	2	3	4	5	6	1′	2′	3′	4′	5′	6′	7′	C(R)
H3	147.3	129.0	115.6	149.6	113.2	116.8	35.1	142.7	115.5	157.2	112.6	128.0	119.5	-
H6	147.2	128.7	115.4	149.6	113.0	116.8	34.5	132.0	115.3	144.9	143.1	116.2	119.4	-
H7	145.0	122.2	114.6	153.2	111.9	114.9	27.5	133.5	144.6	118.0	141.5	110.5	117.2	-
H8	147.7	129.1	115.7	150.2	113.5	117.0	35.6	142.9	114.8	159.7	110.9	128.4	121.3	54.6 (OCH$_3$)
H11	152.8	134.3	119.9	155.1	117.7	122.1	40.2	137.6	118.2	152.1	149.6	121.0	124.5	60.4 (OCH$_3$)
H12	147.6	129.1	115.9	150.1	113.5	116.9	35.6	134.1	106.9	148.3	131.5	148.3	106.9	56.4 (OCH$_3$)
H13	147.5	128.8	115.7	150.0	113.4	117.1	35.2	138.6	128.8	126.1	146.0	126.1	128.8	33.6 (-CH-), 23.8 (-CH$_3$)

Table 3.4 The ^{1}H and ^{13}C chemical shift assignments of **H16** and **H20**
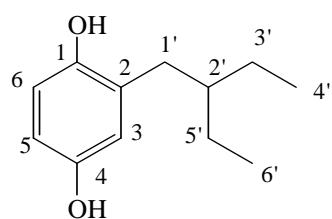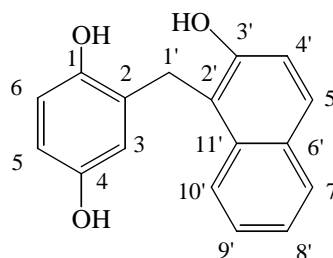
H16   **H20**

Position	H16		Position	H20	
	[1]H	[13]C		[1]H	[13]C
OH	8.45, 8.40 (s, 1H each)	-	OH	9.31 (s)	-
1	-	148.2	1	-	143.5
2	-	128.6	2	-	130.1
3	6.35-6.41 (m, 1H)	115.8	3	6.79 (d, 1H, J=2.8)	115.5
4	-	149.8	4	-	148.8
5	6.35-6.41 (m, 1H)	113.2	5	6.67 (dd, 1H, J=8.0, 2.8)	111.5
6	6.53 (d, 1H, J=8.4)	117.6	6	7.29 (d, 1H, J=9.0)	117.3
1′	2.35 (d, 2H, J= 7.2)	34.1	1′	4.33 (s, 2H)	24.7
2′	1.46-1.49 (m, 1H)	40.4	2′	-	115.2
3′	1.21 (quin, 2H, J=6.0)	25.1	3′	-	153.6
4′	0.80 (t, 3H, J=7.2)	11.1	4′	6.98 (d, 1H, J=8.8)	118.1
5′	1.21 (quin, 2H, J=6.0)	25.1	5′	7.85 (d, 1H, J=8.8)	128.7
6′	0.80 (t, 3H, J=7.2)	11.1	6′	-	127.3
			7′	7.93-7.96 (m, 1H)	128.8
			8′	7.50 (t, 1H, J=7.6)	123.0
			9′	7.63 (t, 1H, J=8.0)	124.6
			10′	7.93-7.96 (m, 1H)	120.5
			11′	-	132.1

3.1.3 2-Alkylated-1,4-benzoquinones

In order to examine the antioxidant property of related compounds of synthesized 2-alkylated hydroquinones, some aforementioned synthetic 2-alkylated hydroquinones were oxidized to the corresponding 2-alkylated-1,4-benzoquinone. The oxidation was performed at room temperature under the atmospheric pressure of oxygen employing cobalt (II) salen as catalyst [25].
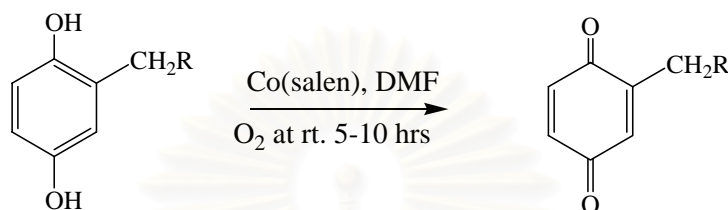

Figure 2.2 demonstrates the structures of four synthesized 2-alkylated-1,4-benzoquinones: 2,6-dimethoxy-1,4-benzoquinone **(Q1)**, 2-benzyl-1,4-benzoquinone **(Q2)**, 2-(3-hydroxybenzyl)-1,4-benzoquinone **(Q3)** and 2-(4-methoxybenzyl)-1,4-benzoquinone **(Q4)**. **Q2**-**Q4** were achieved by the oxidation of **H1**, **H3** and **H9**, respectively, while **Q1** was obtained from that of 2,6-dimethoxyphenol. **Q3** was found to be another additional new compound.
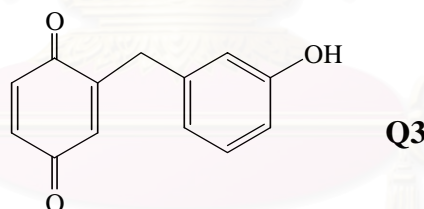
3.1.4 Spectroscopy of 2-alkylated-1,4-benzoquinones

All synthetic 2-alkylated-1,4-benzoquinones were also confirmed their identities by IR and ^{1}H-NMR. **Q3** was in addition especially characterized by ^{13}C-NMR data. The IR, ^{1}H- and ^{13}C-NMR spectra of **Q3** are collected as shown in Appendix A (Figures A.28-A.30).

Infrared Spectroscopy (IR)

The IR spectrum pattern for all synthesized 2-alkylated-1,4-benzoquinones exhibited absorption peaks of hydroxyl group around 3300 cm^{-1}, C-H bond of aromatic ring signal at 3058-3062 cm^{-1}, carbonyl group at 1650 cm^{-1} and double bond of aromatic signal at 1600, 1500 cm^{-1}. The tentative assignments of IR spectrum of **Q3** are tabulated in Table 3.5.

Table 3.5 The IR absorption band assignment of **Q3**

Wave number (cm^{-1})	Intensity	Tentative assignment
3253	medium	O-H stretching vibration of hydroxyl group
3058	weak	C-H stretching vibration
1645	strong	C=O stretching vibration of carbonyl group
1583, 1486	medium	C=C stretching vibration of aromatic

*Nuclear magnetic resonance spectroscopy (NMR)*
^{1}H-NMR

The ^{1}H-NMR spectra of synthesized 2-alkylated-1,4-benzoquinones exhibited the chemical shift of aromatic and olefinic protons around δ 6.0-7.2, protons of methylene and methoxy groups approximately at δ 3.7-3.8. The proton assignments of **Q3** are summarized in Table 3.6.

^{13}C-NMR

According to the ^{13}C-NMR spectrum of **Q3**, the important signals are visualized as follows: the carbonyl signal around δ 190, aromatic and olefinic carbons around δ 120-160 and methylene carbon approximately at δ 40. The carbon signals of **Q3** are assigned as presented in Table 3.6.

Table 3.6 The ^{1}H and ^{13}C chemical shift assignments of **Q3**
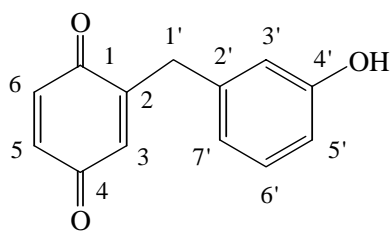
Position	^{1}H	Position	^{13}C
OH	-*	OH	-
1	-	1	192.6
2	-	2	162.4
3, 5, 6, 5′, 7′	6.71-6.83 (m, 5H)	3	143.7
4	-	4	193.1
1′	3.73 (s, 2H)	5	141.6
2′	-	6	142.0
3′	6.44 (s, 1H)	1′	39.8
4′	-	2′	138.1
6′	7.23 (t, 1H, J=7.8)	3′	121.3
*not detected		4′	153.8
		5′	118.9
		6′	134.3
		7′	124.7

3.2 Solubility of 2-alkylated hydroquinones

The solubility test was performed following the methodology described in Chapter II to explore the solubility of all synthesized 2-alkylated hydroquinones. Eleven polar and non polar solvents such as ethyl acetate, dicholoromethane, hexane, toluene *etc* were tried. The results are summarized as shown in Table 3.7.

The obtained result revealed that all synthetic 2-alkylated hydroquinones are quite soluble in polar solvents such as methanol and ethyl acetate more than in non-polar solvents such as hexane and isooctane. In addition, all compounds do not absolutely dissolve when water was used as solvent.

According to their solubility, it was noticeable that these compounds were highly polar compounds which may stem from hydroxyl substituent. Therefore, the synthesized hydroquinones probably do not dissolve in lube base oil since it behaved as a non-polar solvent.

.

Table 3.7 Solubility of synthesized 2-alkylated hydroquinones

Compound	Acetone	CH$_2$Cl$_2$	EtOAc	H$_2$O	MeOH	Isooctane	THF	DMF	Ether	Hexane	EtOH
H1	+++	+++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H2	+++	+++	+++	- , -	+++	+ , +	+++	+++	+++	+ , +	+++
H3	+++	+ , +	+++	+ , +	+++	- , -	+++	+++	+++	- , -	+++
H4	+++	+ , +	+++	- , -	+++	- , -	+++	+++	+++	+ , +	+++
H5	+++	+ , +	++ , ++	- , -	+++	- , -	+++	+++	++ , ++	- , -	+++
H6	+++	+ , +	+++	+ , +	+++	- , -	+++	+++	++ , ++	- , -	+++
H7	+++	+ , +	+++	- , +	+++	- , -	+++	+++	+++	- , -	+++
H8	+++	+++	+++	- , -	+++	+ , +	+++	+++	+++	- , -	+++
H9	+++	+++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H10	+++	+ , +	++ , ++	- , +	+++	- , -	+++	+++	+ , +	- , -	+++
H11	+++	+ , +	+++	+ , +	+++	- , -	+++	+++	++ , ++	+ , +	+++
H12	+++	+ , +	+++	- , -	+++	- , -	+++	+++	+++	+ , +	+++
H13	+++	+++	+++	- , -	+++	+ , +	+++	+++	+++	- , -	+++
H14	+++	++, ++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H15	+++	++ , ++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H16	+++	+ , +	+++	- , +	+++	- , -	+++	+++	+++	- , -	+++
H17	+++	+++	+++	- , -	+++	+ , +	+++	+++	+++	- , -	+++
H18	+++	+++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H19	+++	++ , +++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++
H20	+++	+++	+++	- , -	+++	- , -	+++	+++	+++	+ , +	+++
H21	+++	+++	+++	- , -	+++	- , -	+++	+++	+++	- , -	+++

* , *: at room temperature, after heating at water bath

+++: absolutely soluble, ++: moderately soluble, +: slightly soluble

 -: not dissolve

3.3 Preliminary study on antioxidant activity

Scavenging effect on DPPH radical

The DPPH assay was performed to preliminarily study on antioxidant activity of synthetic hydroquinones and related benzoquinones. The most potent compounds were further examined on antioxidant experiment in lube base oil.

3.3.1   TLC autographic assay

This qualitative analysis was accomplished by the protocol described in Chapter II to preliminary screen for DPPH scavenging assay of all synthesized 2-alkylated hydroquinones and 2-alkylated-1,4-benzoquinones. As an illustrative example, the chromatograms of **H6** and **H7** before and after spraying with DPPH radical reagent are demonstrated in Figure 3.1.

(A)   (B)
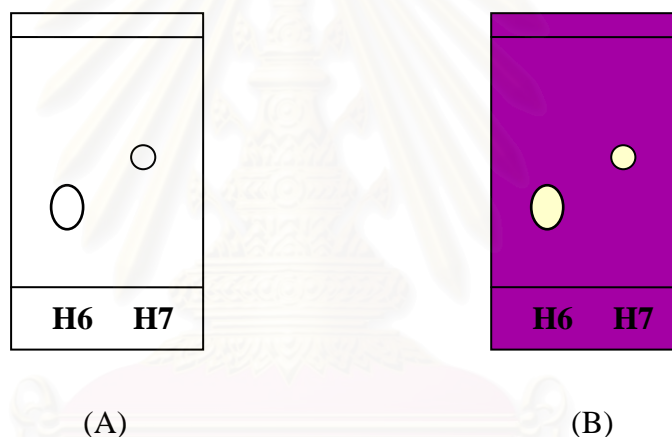
Figure 3.1 TLC autographic assay for DPPH radical scavenger

(A) TLC chromatogram before spraying with DPPH reagent

(B) TLC chromatogram after spraying with DPPH reagent

Figure 3.1A shows the TLC of **H6** and **H7** which was developed in 50% ethyl acetate: hexane before spraying with DPPH. After sprayed with DPPH reagent, the active compounds were immediately visualized as yellow spot against purple background (Figure 3.1B). The results of TLC autographic assay for DPPH radical scavenger of all synthesized 2-alkylated hydroquinones and 2-alkylated-1,4-benzoquinones are collected as presented in Table 3.8.

Table 3.8 TLC autographic assay for DPPH radical scavenger

(A) The result of synthesized 2-alkylated hydroquinones

Compound	Activity	Compound	Activity	Compound	Activity
H1	++	**H8**	++	**H15**	++
H2	++	**H9**	++	**H16**	++
H3	++	**H10**	++	**H17**	++
H4	++	**H11**	++	**H18**	++
H5	+	**H12**	++	**H19**	++
H6	++	**H13**	++	**H20**	++
H7	++	**H14**	++	**H21**	++

(B) The result of synthesized 2-alkylated-1,4-benzoquinones

Compound	Activity
Q1	-
Q2	-
Q3	-
Q4	-

++: immediately, +: about 5 min., -: not bleaching or more than 5 min.

Majority of the compounds in hydroquinone series bleached DPPH reagent immediately to yellow color. **H5** was the only compound taking longer period of time than the others to turn into yellow color. This can thus be expected that **H5** may give the lowest antioxidant activity in this series.

In the series of 2-alkylated-1,4-benzoquinones, **Q1**, **Q2** and **Q4** could not bleach DPPH reagent, whereas **Q3** could turn the color of DPPH to yellow over the period of 5 minutes.

From these autographic results for antioxidant activities, the most potent series was 2-alkylated hydroquinones. The related benzoquinones were not active or expressed very low activity towards DPPH reagent. Therefore, 2-alkylated-1,4-benzoquinones were not carried out for further examination.

3.3.2 Spectrophotometric assay

This assay was performed following the methodology described in Chapter II. It is the technique based on absorbance from UV-spectrophotometer instrument. Having been measured, the absorbance of each concentration was calculated to %radical scavenging as revealed in Appendix B (Table B.1). IC_{50}, concentration at 50% inhibition, indicating antioxidant ability of each compound was determined by probit analysis between concentration and %radical scavenging as summarized in Table 3.9.

Table 3.9 Spectrophotometric assay of 2-alkylated hydroquinones and related compounds

Compound	IC_{50} (mM)	Compound	IC_{50} (mM)
H1	0.13	**H14**	0.12
H2	0.18	**H15**	0.13
H3	0.13	**H16**	0.13
H4	0.13	**H17**	0.12
H5	0.22	**H18**	0.12
H6	< 0.06	**H19**	0.12
H7	< 0.06	**H20**	0.18
H8	0.11	**H21**	0.14
H9	0.13	hydroquinone	0.13
H10	0.13	TBHQ	0.13
H11	0.10	monoacetyl hydroquinone	no activity
H12	< 0.06	diacetyl hydroquinone	no activity
H13	0.14		

According to Table 3.9, by comparing with the IC_{50} value of TBHQ (a common antioxidant), all tested 2-alkylated hydroquinones could be divided into three classes: comparable, more potent and less activity.

Fifteen compounds, **H1**, **H3**, **H4**, **H8-H11**, **H13-H19** and **H21** revealed comparable activity with TBHQ. Three compounds: **H6**, **H7** and **H12** revealed

significantly the lowest IC_{50} values among compounds studied. This meant that they acted as the potent compounds. The lowest activity or the highest IC_{50} values were found in **H2**, **H5** and **H20**.

Being well coincident with the expectation from TLC autographic assay, **H5** gave the lowest activity (0.22 mM) among all tested substances.

Exception of IC_{50}, three classes of activity can be clearly observed in the difference of %radical scavenging demonstrated in Figure 3.2. The potent compound such as **H6** showed high value in percent of scavenging until the concentration is decreased to 0.0625 mM. Whereas **H3** having comparable activity with TBHQ was obviously found dramatically decreasing the scavenging value at 0.125 mM. For the less activity compound, **H5** revealed fewer %radical scavenging than other ones for all concentrations.
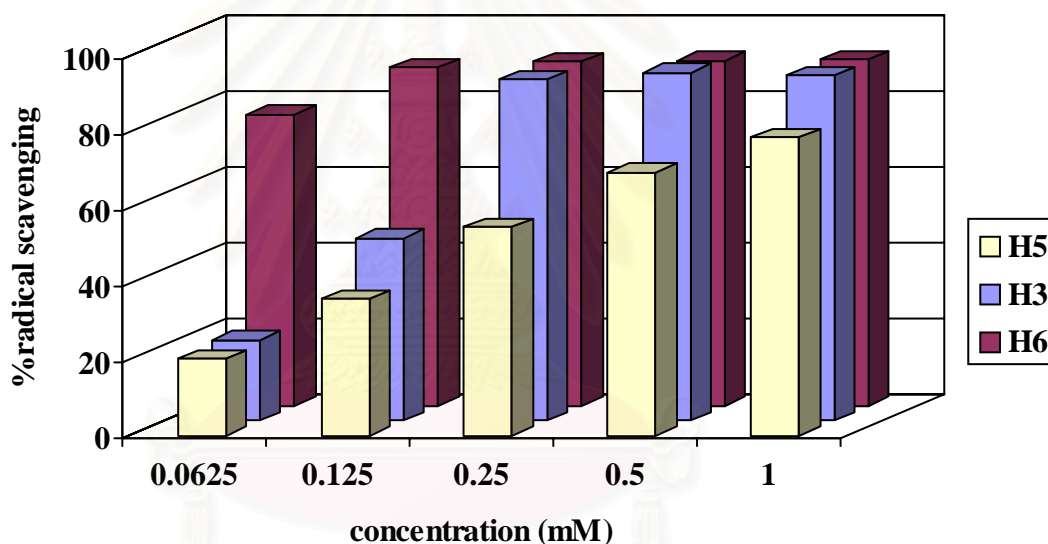
Figure 3.2 The comparison of %radical scavenging of **H5**, **H6** and **H3**

In addition, the spectrophotometric test was also performed for hydroquinone, monoacetyl and diacetyl hydroquinones to examine the effect of hydroxyl group and other substitutents. Hydroquinone showed comparable IC_{50} with TBHQ, while monoacetyl and diacetyl hydroquinones did not scavenge the stable radical.

In conclusion, the most potent compounds displaying radical scavenging activity based on the spectrophotometric assay were found to be **H6, H7** and **H12**. Moreover, these three compounds revealed far better activity than that observed in a commercial antioxidant, TBHQ. Therefore, they are chosen to further test in lube base oil.

3.4 Structure-activity relationships (SARs)

Generally, it is known that there is the correlation between structure and antioxidant activity for phenolic compounds, so called SARs or structure-activity relationships [12]. In this topic, the activities of all synthetic hydroquinone and benzoquinone derivatives and related compounds resulted from the radical scavenging test are relatively considered concerning with their structures. Some factors which affected to antioxidative action of hydroquinone were observed.

| hydroquinone | monoacetyl hydroquinone | diacetyl hydroquinone | TBHQ |
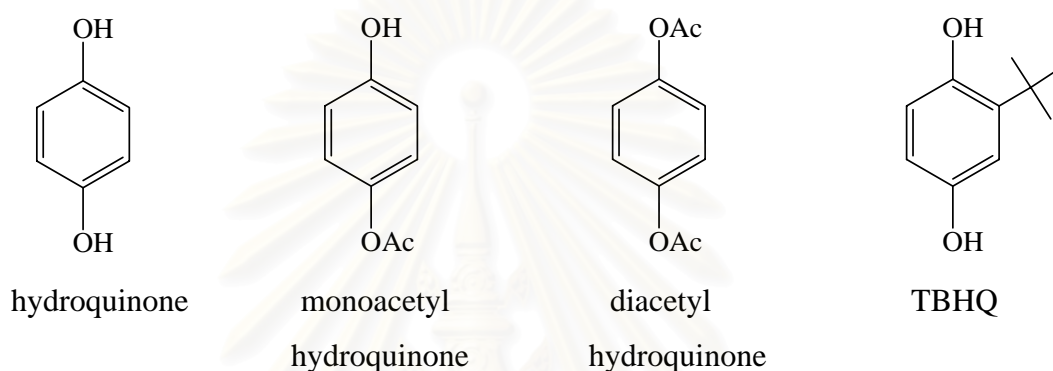
3.4.1   The effect of hydroxyl group

The chain-breaking mechanism of phenolic compounds described in Chapter I revealed that the hydroxyl group acted as important role for their antioxidant activity. The hydrogen abstraction at phenolic proton occurs to scavenge the radical such as alkylperoxyl radical yielding phenoxyl radical.

phenoxyl radical
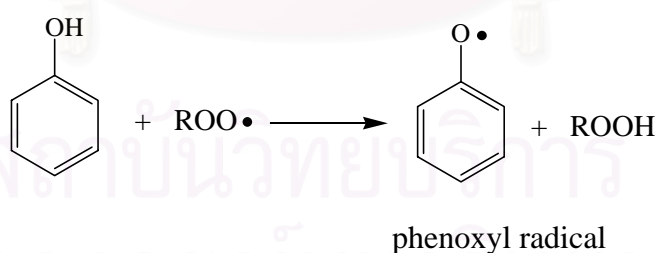
The agreeable results could be observed from both diacetyl hydroquinone and some 2-alkylated-1,4-benzoquinones (**Q1**, **Q2** and **Q4**). These compounds were inactive towards DPPH radical due to the absence of hydroxyl substituent.

3.4.2 Resonance effect and electron donating group

Increasing electron density at the oxygen atom to produce stabilizing phenoxyl radical is an alternative to be able to enhance higher antioxidant. The presence of electron donating group is an important factor for the antioxidant activity of phenolic compounds affecting by resonance [8].

In the case of monoacetyl hydroquinone, it can be clearly observed that the resonance effect was in a controversial way. Instead of stabilization, acetyl group, an electron-withdrawing group, decreased the electron density at oxygen atom resulting destabilizing phenoxyl radical. Therefore, this compound gave similar result as that being absence of hydroxyl group such as diacetyl hydroquinone.

3.4.3 The effect of *ortho*-alkyl group of 2-alkylated hydroquinones
The alkyl group having α–hydrogen atom

Previous studies reported that existing alkyl group, especially benzyl group, at *ortho* position was able to improve antioxidant activity in monophenolic compound [9, 10]. This can be suggested by intramolecular α–hydrogen transfer of α-alkyl proton to phenoxyl radical yielding a new active phenol (equation 3.1). This phenomenon can occur due to more stable benzyl radical intermediate than phenoxyl radical and more stable *o*-(α-peroxy-alkyl)-phenol product than quinonoid type compound (equation 3.2)[28].

$$(3.1)$$

phenoxyl radical   benzyl radical   *o*-(α-peroxy-alkyl)-phenols

$$(3.2)$$

quinonoid type [28]
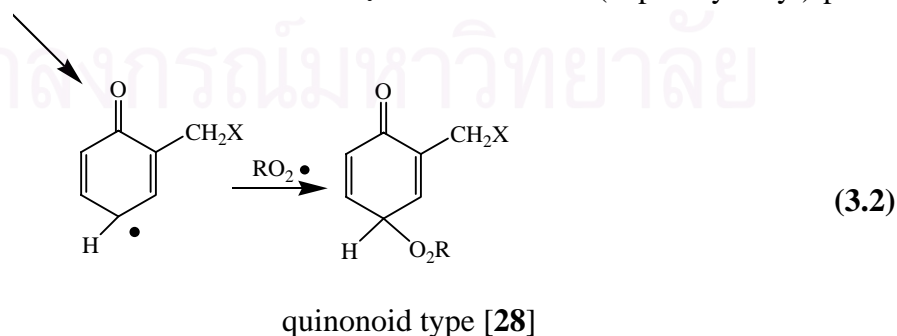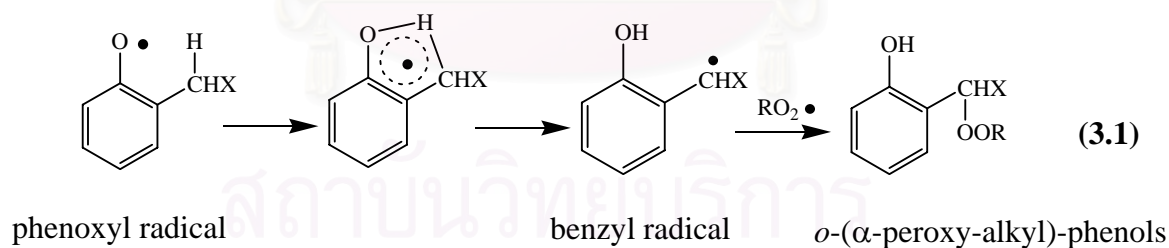
In this research, eight compounds in four *ortho*-alkyl types: **H1** (benzyl group), **H14**, **H15** (substituent group containing heterocyclic group), **H16**-**H18** (long alkyl chain group), **H19** and **H21** (polyaromatic group) having an α–hydrogen atom were considered for their antioxidant activities. Although all these synthesized compounds could proceed intramolecular α–hydrogen transfer resulting various stable alkyl radicals by the influence of each *ortho*-alkyl group, their IC_{50}'s have not differed significantly comparing with that of unsubstituted-hydroquinone. This was implied that pathway (3.1) did not occur for hydroquinones. It was possibly because 1,4-benzoquinone generated by common pathway of hydroquinone action (similar to pathway (3.2)) was much more stable than the product obtained from α–hydrogen transfer pathway (equation 3.1).

The bulkier alkyl group

For monophenolic compounds, the bulkier substituents such as *tert*-butyl at *ortho*- and/or *para*-positions have been reported to inhibit coupling reaction of phenoxyl radicals resulting in increasing of antioxidant activity [**29**]. For example, the coupling reaction of BHT or butylated hydroxytoluene was shown below.

The coupling product of BHT [**30**]
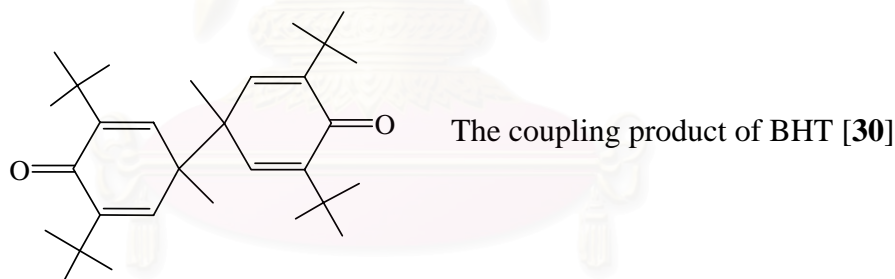
However, the effect of bulky group was not found in the hydroquinone series examined. The IC_{50} of TBHQ revealed the same value as that of unsubstituted hydroquinone. The suggestion of this would have been explained similarly to its α–hydrogen effect. Inhibition of the coupling reaction might have been induced by the formation of the more stable benzoquinone instead of bulkier substituent.

In summary, existing of *ortho*-alkyl substitutents in hydroquinones did not improve their antioxidant activity. Both of α–hydrogen transfer pathway and coupling reaction inhibition by *ortho*-alkyl might not have taken place in this series due to the formation of more stable benzoquinone from common pathway.

3.4.4 The effect of substitutent of *ortho*-alkyl group

The electron-donating groups such as hydroxyl, methoxy and isopropyl group at the *ortho*-alkyl group especially *o*-benzyl group were examined for their antioxidant activity.

Type and position of electron-donating group

The effect of type of diverse electron-donating groups at *o*-benzyl moiety was considered in the case of **H1**, **H4**, **H9** and **H13**. Their IC_{50}'s did not significantly show different value. The outcome was in good agreement with the expectation that α–hydrogen transfer pathway of hydroquinone did not prefer [**28**]. Therefore, these electron donating groups did not influence the activity of four hydroquinones. Moreover, the effect of position could clearly be visualized from the IC_{50}'s between **H3** *vs* **H4** and **H8** *vs* **H9**. The comparable activity among observed compounds confirmed that the hydrogen transfer of hydroquinone did not exist.

3.4.5 The effect of hydroxyl substituent of *ortho*-alkyl group

The noticeable result was especially found in the synthesized hydroquinones existing hydroxyl substituents at *o*-alkyl group.

Antioxidative action part of polyaromatic phenol

In previous report, ESR and electrochemical studies showed that the oxidation of polyaromatic phenols took place only in one ring. This was in fact depended on the ease of hydrogen abstraction at hydroxyl groups in each ring, indicated by stable phenoxyl radical produced [**31**].

For **H2**-**H4**, the oxidation could take place in *o*-benzyl ring besides the hydroquione part. However, hydrogen abstraction at hydroquinone part occurred more easily than that at *o*-benzyl ring due to more stable phenoxyl radical. Therefore, the antioxidative action of these compounds preferably occured in hydroquinone part resulting comparable IC_{50} with unsubstitued hydroquinone.

In the case of **H11**, although adjacent methoxy group can stabilize phenoxyl radical obtained from *o*-benzyl part by resonance effect, phenoxyl from hydroquinone part was still more stable radical than that derived from *o*-benzyl part. This was clearly seen by comparable IC_{50} with both **H2**-**H4** and unsubstitued hydroquinone.

A major evidence could be observed from **H6**, **H7** and **H12** that the *o*-benzyl group played an important role for their activity. From their IC$_{50}$, these three compounds significantly displayed the highest activity among all tested hydroquinones. This implied that their antioxidative action did not take place in hydroquinone part, but in *o*-benzyl ring. In **H12**, this phenomenon could be explained by the resonance effect of two adjacent methoxy groups at *o*-benzyl ring. Whereas such good activity observed in **H6** and **H7**, supported by the occurrence of more stable phenoxyl at *o*-benzyl could be explained by resonance effect, intramolecular hydrogen bonding, dimerization of 1,2-dihydroxyphenol and combination with oxygen atom.

Intramolecular hydrogen bonding

Catechol or 1,2-dihydroxyphenol characteristic exists on *o*-benzyl group of **H6** and **H7**. Phenoxyl radical yielded from antioxidative action of this character can form intramolecular hydrogen bonding. This can stabilize the phenoxyl to be more stable radical than that of hydroquinone part due to decreasing the radical energy [**7**, **31**].

(3.3)
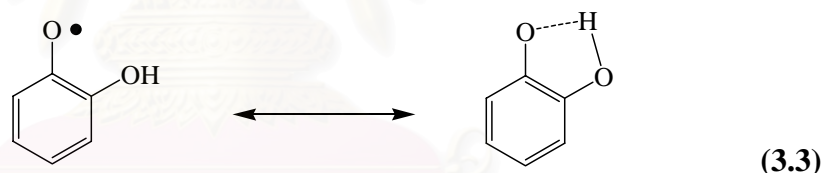
Dimerization of 1,2-dihydroxyphenol

Previous study has reported that antioxidative product of catechol, 1,2-benzoquinone, could undergo dimerization and resulted in regenerating a new antioxidant (equation 3.4). This pathway promoted the catechol to be more reactive than hydroquinone part [**31**].

(3.4)
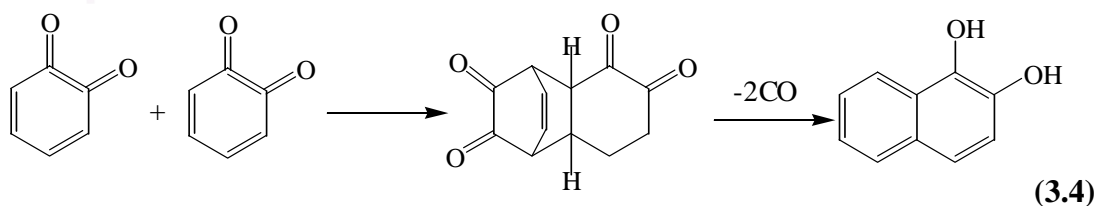
Combination with oxygen atom

Previous researches have addressed on the electrochemical oxidation potential (E_p) of dihydroxyphenol such as hydroquinone, catechol and resorcinol (1,3-dihydroxy phenol). The lowest E_p value of hydroquinone indicated that the hydrogen abstraction facilely occurred [7]. However, phenoxyl radical of hydroquinone could react easily with molecular oxygen (equation 3.5) due to formation of much more stable 1,4-benzoquinone products. Instead of termination, this process was propagation step and initiated more reactive hydroperoxide radical. The combination deactivated the antioxidative action of hydroquinone [31, 32].

$$(3.5)$$
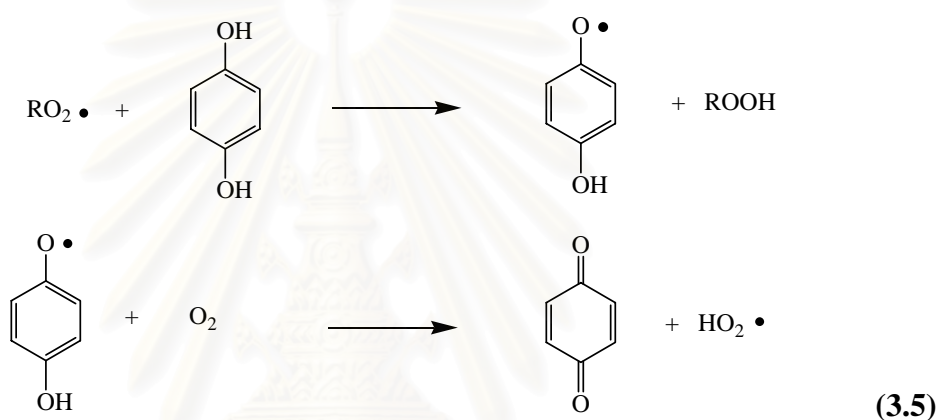
3.4.6   The steric effect

Three hydroquinones including **H2**, **H5** and **H20** showed less efficiency. Existing only one hydroxyl substituent, *o*-benzyl group of **H2** and **H20** produced less stable phenoxyl radical than hydroquinone part. Whereas in the case of **H5**, resorcinol played as monohydric compound caused by little resonance stabilization effect at *meta* position [31]. Thus, the antioxidative action of these compounds might take place on hydroquinone part and result comparable ability with **H1** or non substituted hydroquinone. This expectation, however, disagreed with the result attained. It could noticeably observe that these compounds had 2-hydroxyl group at *o*-alkyl group. It was possible that this group hindered the approach of a peroxyl radical at active site of hydroquinone part.

3.5 Laurylation of 2-alkylated hydroquinones

To improve the solubility in lube base oil, the long chain alkylation was performed in the potent antioxidant compounds such as **H6**, **H7** and **H12**. Lauryl alcohol having 12 carbon atoms was utilized as an alkylating agent. The alkylation was performed by the procedure described in Chapter II. 85% Phosphoric acid and toluene were used as catalyst and solvent, respectively [**27**].
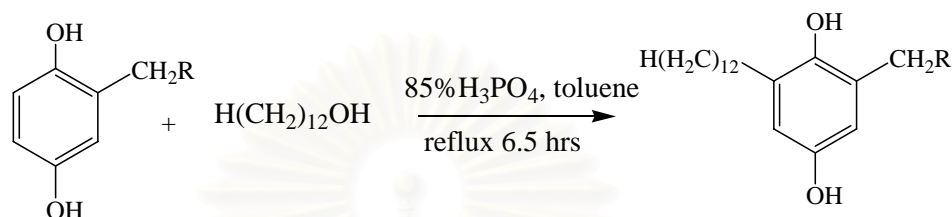
3.5.1   2-Alkylated-6-lauryl hydroquinones

Two 2-alkylated-6-lauryl hydroquinones were accomplishly synthesized. LTBHQ (2-*t*ert-butylated-6-lauryl hydroquinone, **L1**) was obtained by laurylation of TBHQ (*tert*-butylated-hydroquinone) [**27**] while 2-(4-methoxybenzyl)-6-lauryl hydroquinone **(L2)** was derived from **H9** as model of alkylation of synthesized hydroquinones. **L2** was found to be another additional new compound (structure below).

L2
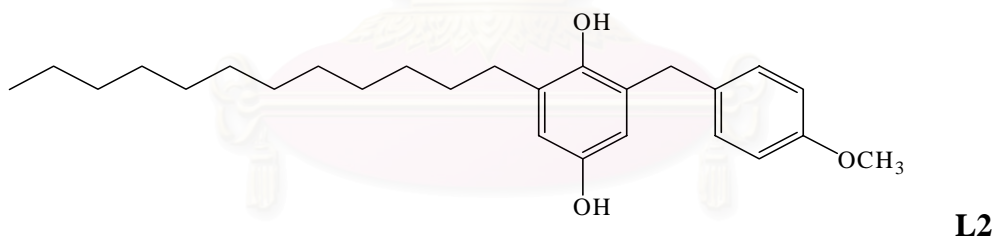
The lauryl group can basically attach either at 5- or 6- position of hydroquinone part. However, the 5-isomer was attained in lower ratio than the 6-isomer due to inductive effect [**27**].

For the potent compounds, **H6, H7** and **H12**, the attempts of laurylation reactions were not successful. That might be influenced from the insolubility of hydroquinone in toluene (non polar solvent). Therefore, the other polar solvents such as chloroform and DMF have been tried for the reaction [**33**]; however desired products have still not been achieved. Therefore, these potent compounds were directly used as such in base oil as heterogeneous system for studying the oxidative stability of the oil comparing with **L2**.

3.5.2 Spectroscopy of 2-alkylated-6-lauryl hydroquinones

L1 and **L2** were confirmed their identities by spectroscopic data including IR and ^{1}H-NMR. **L2** as a new compound was in addition characterized by ^{13}C-NMR data. Their spectra were demonstrated in Appendix A (Figures A.31-A.33).

Infrared spectroscopy (IR)

The IR absorption pattern for all synthesized 2-alkylated-6-lauryl hydroquinones showed the characteristic of common functional group. To illustrate this, the O-H stretching vibration of hydroxyl group around 3300 cm^{-1}, that of C-H stretching of aromatic moiety around 3000 cm^{-1} and that of C=C ring stretching approximately at 1600, 1500 cm^{-1} were also observed. The IR absorption band assignment of **L2** is tabulated in Table 3.10.

Table 3.10 The IR absorption band assignment of **L2**

Wave number (cm^{-1})	Intensity	Tentative assignment
3385	strong	O-H stretching vibration of hydroxyl group
2918	medium	C-H stretching vibration
1610, 1474	medium	C=C stretching vibration of aromatic
1211	strong	C-O stretching vibration

Nuclear magnetic resonance spectroscopy
^{1}H-NMR

The ^{1}H-NMR spectra of **L1** and **L2** show important signals of aromatic protons around δ 6.5-7.2, hydroxyl proton around δ 4.5 and long chain hydrocarbon approximately at δ 0.9-4.0. The chemical shifts of **L2** were tentatively assigned as shown in Table 3.11.

^{13}C-NMR

According to the ^{13}C-NMR spectrum of **L2**, the important signals are visualized as follows: aromatic carbons around δ 110-160, carbon of methoxy group at δ 55, methylene carbon at δ 36 and carbons of long alkyl chain approximately at δ 10-30. The carbon assignments of **L2** are summarized in Table 3.11.

Table 3.11 The ^{1}H and ^{13}C chemical shift assignments of **L2**
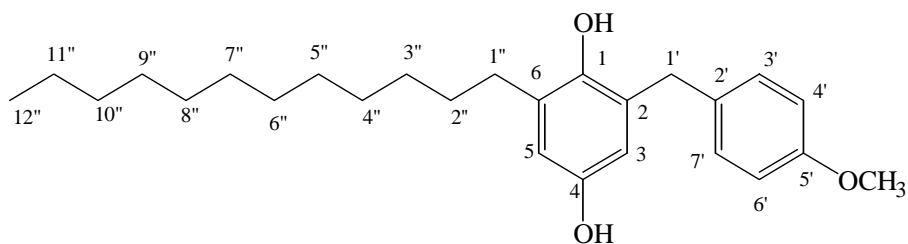
Position	^{1}H	Position	^{13}C
OH	4.38	1	147.5
1, 2, 4, 6	-	2	128.3
3, 5	6.71-6.74 (m, 2H)	3	113.0
1′	3.88-3.93 (m, 2H)	4	153.3
2′	-	5	116.4
3′, 7′	7.18 (d, 2H, J=7.2)	6	117.2
4′, 6′	6.87 (d, 2H, J=8.5)	1′	55.3
1″	3.88-3.93 (m, 2H)	2′	131.5
2″	1.73-1.80 (quin, 2H, J=6.9)	3′, 7′	129.6
3″-11″	1.30-1.33 (m, 18H)	4′, 6′	114.1
12″	0.91 (m, 3H)	5′	158.2
-OC**H**$_3$	3.82 (s, 3H)	1″	26.1
		2″	31.9
		3″-9″	29.4-29.7
		10″	35.9
		11″	22.7
		12″	14.1
		OCH$_3$	68.5

3.6 The effect of 2-alkylated hydroquinones on oxidative stability of lube base oil

Due to unsuccessfulness in laurylation of the potent compounds, the use of surfactant is another alternative way to solve solubility problem. However, previous studies have reported that the surfactant can influence the partition of the active principle to aqueous phase resulting decreasing of their antioxidant activity [**34, 35**].

According to that reason, the potent hydroquinones: **H6**, **H7** and **H12** were directly tested to observe their antioxidant activity in lube base oil evaluated by oxidative stability of lube oil blended with each hydroquinone. **L2** and **H9** were also examined for the effect of solubility on their antioxidant activity. The stability of oil was measured by RBOT (rotary bomb oxidation test) as described in Chapter II.

H6   **H7**   **H12**
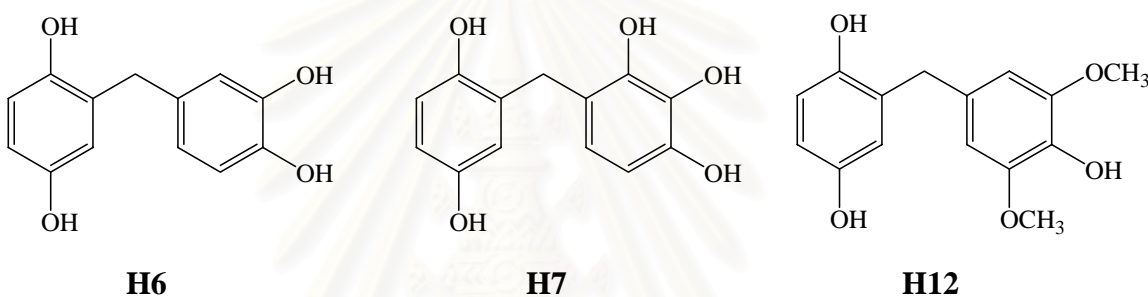
Generally, the amount of antioxidant usually blended in each type of lubricating oils is 0.1-2%w/w. In this test, to receive the least effect from their solubility, 0.1%hydroquinone samples were blended with base oil at $60^{O}C$ for 2 hours. Under oxygen pressure, a large amount of copper catalyst and high temperature, the induction period was measured as the time to pressure drop (25.4 psi) [**14**]. The times of sample oil blended with the potent hydroquinones are shown in Table 3.12.

Table 3.12 Induction period of the potent hydroquinones additive by RBOT

Additive	Amount of additive (% w/w)	Induction period (min)
No additive (neat base oil)	0	22
TBHQ	0.1	24
H6	0.1	43
H7	0.1	43
H9	0.1	35
L2	0.1	34
H12	0.1	55
	0.5	91
	1.0	112

3.6.1   The effect of the solubility of 2-alkylated hydroquinones

Comparing with the induction time of neat base oil, the addition of all synthetic 2-alkylated hydroquinones such as **H6**, **H7**, **H9** and **H12** in base oil can induce the delay of auto-oxidation by showing longer period in oxygen depletion. It was worth noting at this point that the antioxidative action of the synthesized compounds occurred in heterogeneous system.

The solubility effect on the antioxidation action of synthesized hydroquinones was clearly observed by the results of **H9** and **L2**. Although, **L2** could better dissolve in base oil than **H9** due to long alkyl chain, the induction time of both showed comparable values as 35 and 34 minutes for **H9** and **L2**, respectively. This suggested that the antioxidative activities of synthesized hydroquinones do not affect from the solubility problem.
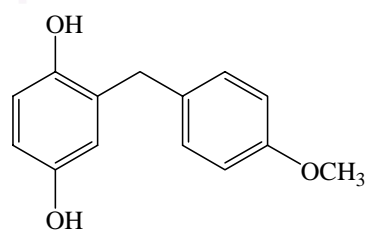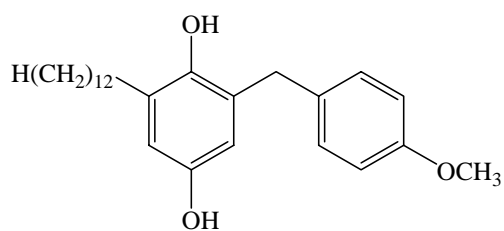
H9   **L2**

3.6.2 The relationship between IC_{50} and induction period

Previous report observed similar tendency between IC_{50} value and induction period [7, 30]. In this research, the assumption was also found in heterogeneous system. The potent compounds to DPPH radical scavenging test: **H6**, **H7** and **H12** still showed longer induction period than **H9** and TBHQ (commercially material). This meant that these compounds can still display as effective antioxidant in lubricating oil.

3.6.3 The effect of concentration

The effect of concentration of the potent compounds on the oxidative stability of the oil was determined by examination of **H12.** Three concentrations such as 0.1, 0.5 and 1%w/w were studied. The IP results of each were plotted in Figure 3.3. A higher percentage of **H12** resulted in longer delays before rapid autoxidation-behavior that was the characteristics of the effects of increased concentration of primary (chain-breaking) antioxidant [18].
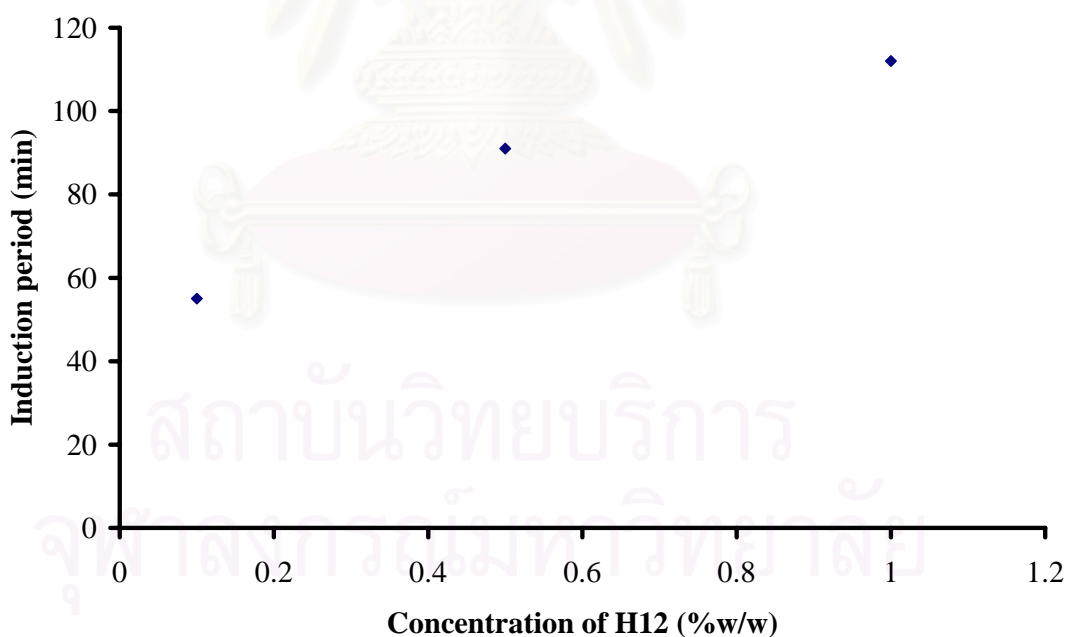
Figure 3.3 The effect of concentration of **H12** (%w/w) on the autoxidation
of lube base oil

However, the corresponding oxidation times in lube base oil blends may not approach linearity for **H12** concentration. It was proposed that the hydrogen abstracted from alkylperoxide by phenoxyl radical may occur at high concentration. The reverse of reaction generated new free radicals resulting in the decrease of their activity [**31**].

$$PhO\bullet + LOOH \longrightarrow PhOH + LOO\bullet$$

$$PhO\bullet + LH \longrightarrow PhOH + L\bullet$$
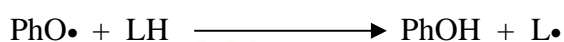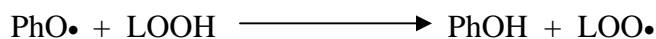
$$(3.6)$$

In conclusion, the potent compounds determined by DPPH test displayed as effective antioxidant in lube base oil compared with TBHQ. The delay of autoxidation in lube base oil can prefer in heterogeneous system. In addition, the solubility problem did not influence to antioxidant activity of the hydroquinones.

CHAPTER IV

CONCLUSION

During the course of this research, with the aim to search for new potent antioxidants in lubricating oils, twenty one 2-alkylated hydroquinones were synthesized from aldol condensation between 1,4-cyclohexanedione and varieties of aldehydes using LiCl and pyridine as catalyst and solvent, respectively. All synthesized hydroquinones could be divided by type of *ortho*-alkyl into mainly four groups: benzyl group (**H1**-**H13**), substituent containing heterocyclic group (**H14**-**H15**), long alkyl chain group (**H16**-**H18**) and polyaromatic group (**H19**-**H21**). Nine synthetic hydroquinones compounds: 2-(3-hydroxybenzyl) hydroquinone (**H3**), 2-(3,4-dihydroxybenzyl) hydroquinone (**H6**), 2-(2,3,4-trihydroxybenzyl) hydro-quinone (**H7**), 2-(3-methoxybenzyl) hydroquinone (**H8**), 2-(4-hydroxy-3-methoxy benzyl) hydroquinone (**H11**), 2-(4-hydroxy-3,5-methoxybenzyl) hydroquinone (**H12**), 2-(4-isopropylbenzyl) hydroquinone (**H13**), 2-(2-ethylbutyl) hydroquinone (**H16**) and 2-(2-hydroxy-1-methylnaphthalenyl) hydroquinone (**H20**) were disclosed as new compounds based upon no report addressed in chemical literature.

Four 2-alkylated 1,4-benzoquinones (**Q1**-**Q4**) were achieved by oxidation of 2,6-dimethoxyphenol, **H1**, **H3** and **H9**, respectively. The oxidation was carried out by utilizing oxygen as an oxidant in presence of cobalt salen and DMF as catalyst and solvent, respectively. 2-(3-Hydroxybenzyl)-1,4-benzoquinone (**Q3**) was found to be another additional new compound.

Both synthesized hydroquinones and benzoquinones were determined for their antioxidant activities by DPPH radical scavenging assay to preliminary study their properties. The qualitative analysis, TLC autographic assay, showed that the related benzoquinones series were not active or expressed very low activity toward DPPH reagent. Therefore, they were not carried out for further examination. For the spectrophotometric assay, the quantitative analysis, the resulted IC_{50} of all synthesized 2-alkylated hydroquinones could be classified into three classes according to the IC_{50} comparing to that of TBHQ, *i.e.*, comparable activity (**H1**, **H3**, **H4**, **H8-H11**, **H13-H19** and **H21**), more potent activity (**H6**, **H7** and **H12**) and less activity (**H2**, **H5** and

H20). The potent hydroquinones were an attractive antioxidant for further studying their antioxidant properties in lubricating oil.

SARs or structure-activity relationships are considered as the relationship between the structures of all tested hydroquinones, benzoquinones, related compounds and their activity. The observation of their IC_{50}'s revealed that hydroquinone series did not exhibit antioxidative action *via* α–hydrogen transfer pathway and inhibition of coupling reaction due to the formation of more stable 1,4-benzoquinone. Thus, the activity of all tested hydroquinone did not affect by *o*-alkyl group and yielded comparable IC_{50} with unsubstituted hydroquinone. For the potent hydroquinones, high activity of these can be explained by the oxidation taking place in *o*-benzyl ring. This part could generate more stable phenoxyl radical than its hydroquinone part. In **H12**, stability of phenoxyl radical at *o*-benzyl ring could be described only by resonance effect. Whereas that of **H6** and **H7** were concerned about resonance effect, intramolecular hydrogen bonding, dimerization and combination with oxygen atom. Noticeable results were also found in less antioxidative activity of **H2**, **H5** and **H20** probably due to steric effect of 2-hydroxyl group at *o*-benzyl ring.

According to the solubility test results, all synthesized hydroquinones displayed as high polar compounds. Therefore, the laurylation reaction was performed for the potent hydroquinones to increase the solubility in lube base oil before they were tested in the oil. However, these reactions were not successful. **L1** and **L2** were especially obtained from the reaction of TBHQ and **H9**, respectively. **L2** was used to study the oxidative stability of base oil on the effect of solubility in RBOT.

Due to unsuccessfulness in long chain alkylation, all potent compounds were directly determined their antioxidant properties in lube base oil by RBOT test. The IP results showed that they could be utilized as an antioxidant in heterogeneous system and exhibited high antioxidant activity to autoxidation of the oil as well as the highest scavenging towards DPPH. For the effect of their solubility, the IP's of **H9** and its analogues bearing a lauryl group (**L2**) were considered. It confirmed that the solubility problem does not influence on the antioxidant activity in the series of hydroquinones. The characteristics of primary antioxidant were observed when the concentrations of **H12** were varied. Increasing of the concentration of this compound gave longer period in oxygen depletion. However, the hydroquinones could combine

with oxygen atom at high concentration resulting non linearity in the relationship between **H12** percentages and their activity.

In conclusion, three synthesized 2-alkylated hydroquinones: **H6**, **H7** and **H12** are new potent antioxidants and exhibited higher antioxidant activity than TBHQ in both scavenging effect on DPPH radical and inhibition effect on autoxidation in lubricating oils.

Proposal for the future work

This research concerned with the improvement of the oxidative stability in lubricant oil by new synthetic antioxidant. The outcome opened many possibilities to deal with future exploration. Other routes of laurylation as well as performing the reaction in substance of the potent hydroquinones should be tried to improve the solubility of the synthesized potent compounds. More effects such as interaction with natural antioxidant and base oil composition should also be investigated to extend the scope of this work. Moreover, it was observed that hydroquinones possessed antifungal activity. The study of all synthetic hydroquinones as biologically active compounds should be another interesting point.

REFERENCES

1. Mang, T.; Dresel, W. *Lubricants and Lubrication*, Wiley-VCH GmbH, Weinheim, **2001**.

2. Boonthrong, S. *Quality Improvement of Heavy Distillate for Lubricating Base Oil by Hydrotreatment.* Master's Thesis, Program of Petrochemistry and Polymer Science, Faculty of Science, Chulalongkorn University, **1993**.

3. Klamann, D. *Lubricants and Related Products: Synthesis, Properties, Applications, International Standards*, Weinheim, Deerfield Beach, Florida; Basel: Verlag Chemie, **1984**.

4. Ampha, R. *Determination of Dispersants in Gasoline and Diesel Oil.* Master's Thesis, Program of Petrochemistry and Polymer Science, Faculty of Science, Chulalongkorn University, **1996**.

5. Rakchitt, S. *Preparation of Metal Dithiophosphates from Isoamyl Alcohol as Lubricant Antioxidant.* Master's Thesis, Program of Petrochemistry and Polymer Science, Faculty of Science, Chulalongkorn University, **1997**.

6. Dantas, T. N. C.; Dantas, M. S. G.; Neto, A. A. D.; D'Ornellas, C. V.; Queiroz, L. R. Novel Antioxidants from Cashew Nut Shell Liquid Applied to Gasoline Stabilization. *Fuel*, **2003**, *82*, 1465-1469.

7. Yamamura, T.; Nishiwaki, K.; Tanigaki, Y.; Terauchi, S.; Tomiyama, S.; Nishiyama, T. Antioxidant Activities of Dihydric Phenol Derivatives for the Autoxidation of Tetralin. *Bull. Chem. Soc. Jpn.*, **1995**, *68*, 2955-2960.

8. Scott, G. Antioxidants. *Bull. Chem. Soc. Jpn.*, **1988**, *61*, 165-170.

9. Yamada, F.; Nishiyama, T.; Suzuura, Y.; Yamamura, T. Benzylphenol Derivatives as Antioxidants for Autoxidation of Tetralin. *Bull. Chem. Soc. Jpn.*, **1985**, *58*, 115-119.

10. Yamada, F.; Nishiyama, T.; Yamamoto, M.; Tanaka, K. Substituted Bisphenols as Antioxidants for Autoxidation of Tetralin. *Bull. Chem. Soc. Jpn.*, **1989**, *62*, 3603-3608.

11. Nishiyama, T.; Sugimoto, T.; Miyamoto, N.; Uezono, M.; Nakajima, Y. Antioxidant Activities of Phenols having a Fused Oxygen-Containing Heterocyclic Ring. *Polym. Degrad. Stab*., **2000**, *70*, 103-109.

12. Nenadis, N.; Zhang, H. Y.; Tsimidou, M. Structure-Antioxidant Activity Relationship of Ferulic Acid Derivatives: Effect of Carbon Side Chain Characteristic Groups. *J. Agric. Food Chem.*, **2003**, *51*, 1874-1879.

13. Cermak, S. V.; Isbell, T. A. Improved Oxidative Stability of Estolide Esters. *Ind. Crops Prod.*, **2003**, *18*, 223-230.

14. American Society for Testing Materials, Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Bomb, *ASTM (D2272-85)*, **1989**, *05.02*, 113-120.

15. Napgal, J. M.; Joshi, G. C.; Rastogi, S. N. Stability of Cracked Naphthas from Thermal and Catalytic Processes and Their Additive Response: Part I. Evaluation of Stability and Additive Response. *Fuel*, **1995**, *74*, 714-719.

16. Napgal, J. M.; Joshi, G. C.; Rastogi, S. N. Stability of Cracked Naphthas from Thermal and Catalytic Processes and Their Additive Response: Part II. Composition and Effect of Olefinic Structures. *Fuel*, **1995**, *74*, 720-724.

17. Jones, E. G.; Balster, W. Phenomenological Study of the Formation of Insolubles in a Jet-A Fuel. *Energy and Fuels*, **1993**, *7*, 968-977.

18. Jones, E. G.; Balster, W. Interaction of a Synthetic Hindered-Phenol with Natural Fuel Antioxidants in the Autoxidation of Paraffins. *Energy and Fuels*, **2000**, *14*, 640-645.

19. Tian, G.; Xia, D.; Zhan, F. The Oxidation of Tetralin and Its Effect on the Stability of Fluidized Catalytic Cracked Diesel. *Energy and Fuels*, **2004**, *18*, 49-53.

20. Adhvaryu, A.; Erhan, S. Z. Epoxidized Soybean Oil as a Potential Source of High-Temperature Lubricants. *Ind. Crops Prod.*, **2002**, *15*, 247-254.

21. Sharma, B. K.; Stipanovic, A. J. Development of a New Oxidation Stability Test Method for Lubricating Oils Using High-Pressure Differential Scanning Calorimetry. *Thermochim. Acta*, **2003**, *402*, 1-18.

22. Ozaki, Y.; Hosoya, A.; Okamura, K,; Kim, S. W. A Convenient Synthesis of 2-Alkylated 1,4-Benzenediols. *Synlett*, **1997**, 365-366.

23. Takao, T.; Kitatani, F.; Watanabe, N.; Yagi, A.; Sakata, K. A Simple Screening Method for Antioxidants and Isolation of Several Antioxidants

Produced by Marine Bacteria from Fish and Shellfish. *Biosci. Biotech. Biochem*, **1994**, *58*, 1780-1783.

24. Hosttettmann, K.; Terreaux, C.; Marston, A.; Potterat, O. The Role of Planar Chromatography in the Rapid Screening and Isolation of Bioactive Compounds from Medicinal Plants. *J. Pla. Chro.*, **1997**, *10*, 251-257.

25. Imurai, J. *Oxidation of Phenols by Transition Metal Schiff-Base Catalysts.* Master's Thesis, Program of Petrochemistry and Polymer Science, Faculty of Science, Chulalongkorn University, **2002**.

26. Vogel, A. I. *A Text-Book of Practical Organic Chemistry*, **1948**, 914-915.

27. Zhang, C. X.; Wu, H.; Weng, X. C. Two Novel Synthetic Antioxidants for Deep Frying Oils. *Food Chem.*, **2004**, *84*, 219-222.

28. Ohkatsu, Y.; Ishikawa, S. I.; Tobita, E. Consideration on the Effect of *Ortho*-Substituents of Phenols by Semiempirical Molecular Orbital Method MOPAC. *Polym. Degrad. Stab.*, **2000**, *67*, 541-545.

29. Howard, J. A.; Ingold, K. U. The Inhibition Autoxidation of Styrene: Part III. The Relative Inhibiting Efficiencies of *Ortho*-Alkyl Phenols. *Can. J. Chem.*, **1963**, *41*, 2800-2806.

30. Ohkatsu, Y.; Nishiyama, T. Phenolic Antioxidants-Effect of *Ortho*-Substituents. *Polym. Degrad. Stab.*, **2000**, *67*, 313-318.

31. Litwinienko, G.; Kasprzycka-Guttman, T.; Jamanek, D. DSC Study of Antioxidant Properties of Dihydroxyphenols. *Thermochim. Acta*, **1999**, *331*, 79-86.

32. Roginsky, V.; Barsukova, T.; Loshadkin, D.; Pliss, E. Substituted *p*-Hydroquinones as Inhibitors of Lipid Peroxidation. *Chem. Phys. Lipids*, **2003**, *125*, 49-58.

33. Weng, J. Preparation of aliphatic alkyl substituted tert-butyl-1,4-benzoquinone derivatives as antioxidant. *CN patent 1380280* Nov. 20, 2002.

34. Frankel, E. N.; Huang, S. W.; Kanner, J.; German, J. B. Interfacial Phenomena in the Evaluation of Antioxidants: Bulk Oils vs Emulsion. *J. Agric. Food Chem.*, **1994**, *42*, 1054-1059.

35. Richards, M. P.; Chaiyasit, W.; McClements, D. J.; Decker, E. A. Ability of Surfactant Micelles to Alter the Partitioning of Phenolic Antioxidants in Oil-in-Water Emulsions. *J. Agric. Food Chem.*, **2002**, *50*, 1254-1259.

APPENDICES
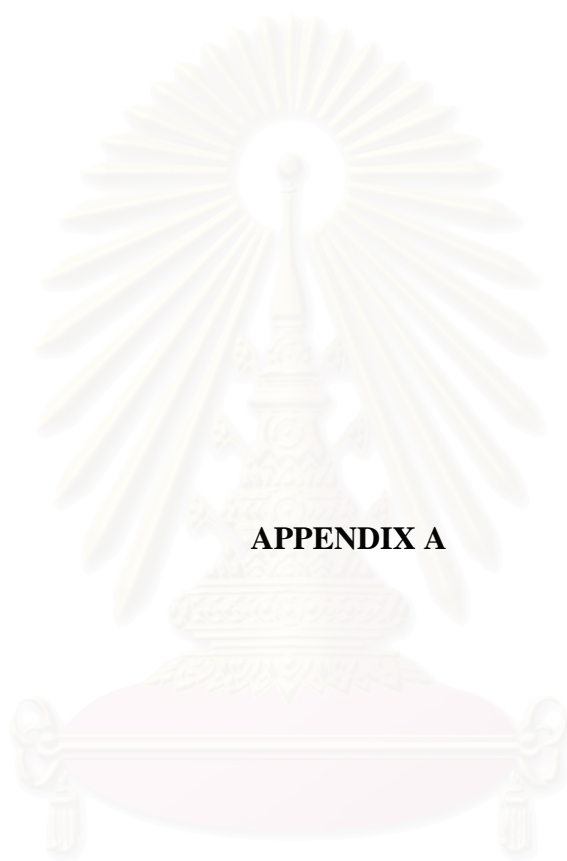
APPENDIX A
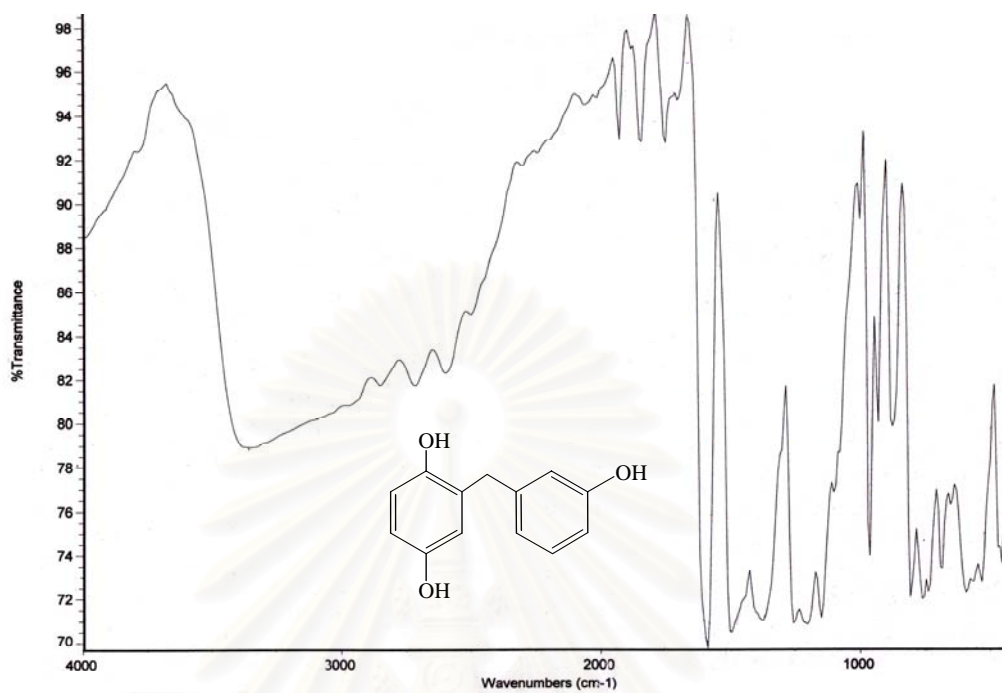
Figure A.1 The IR spectrum of **H3**
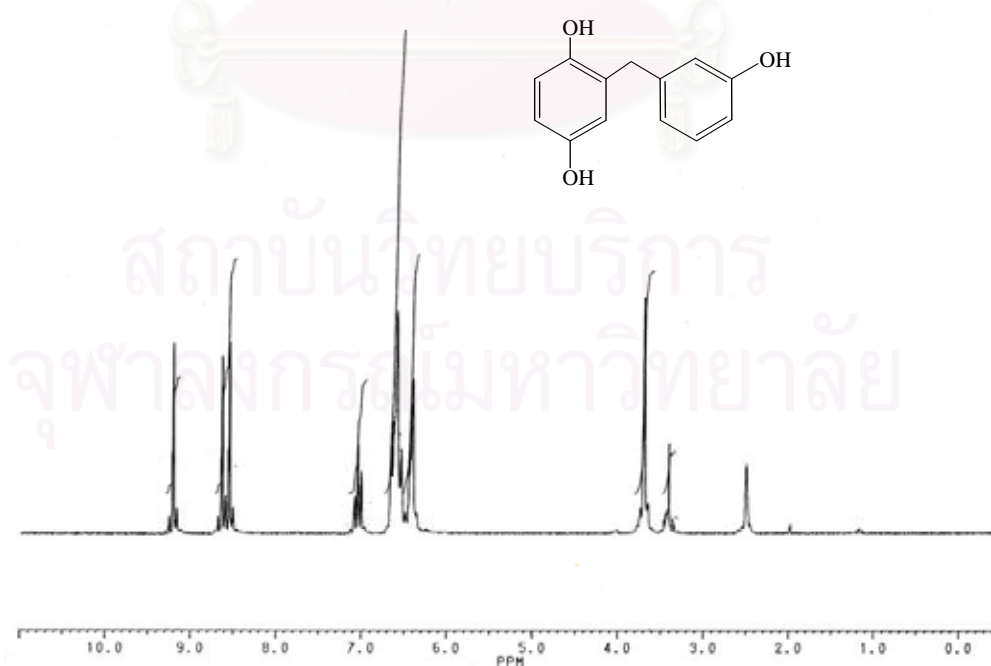
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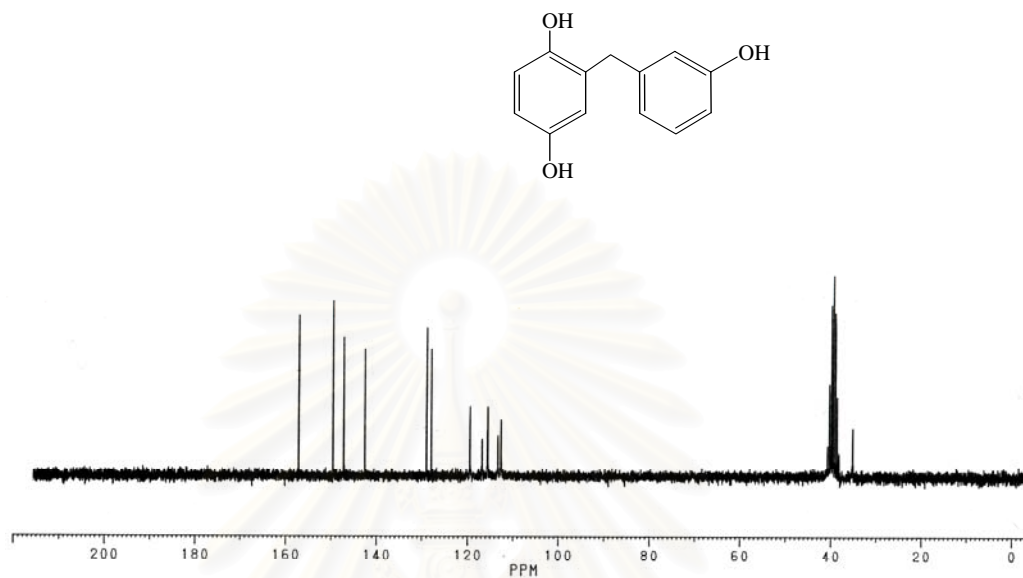
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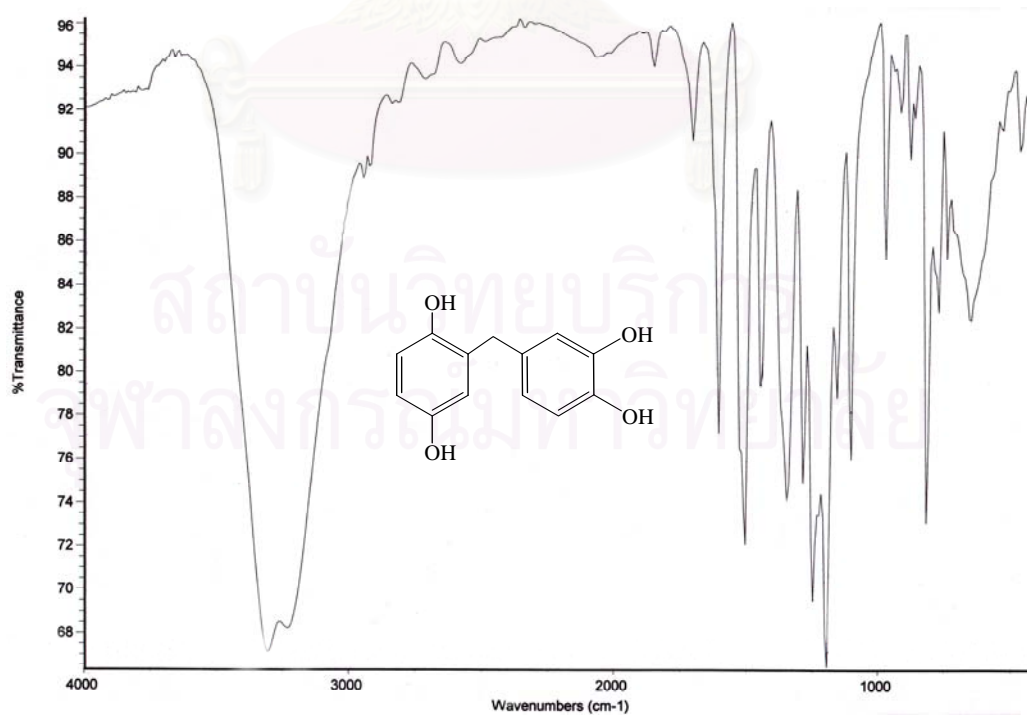
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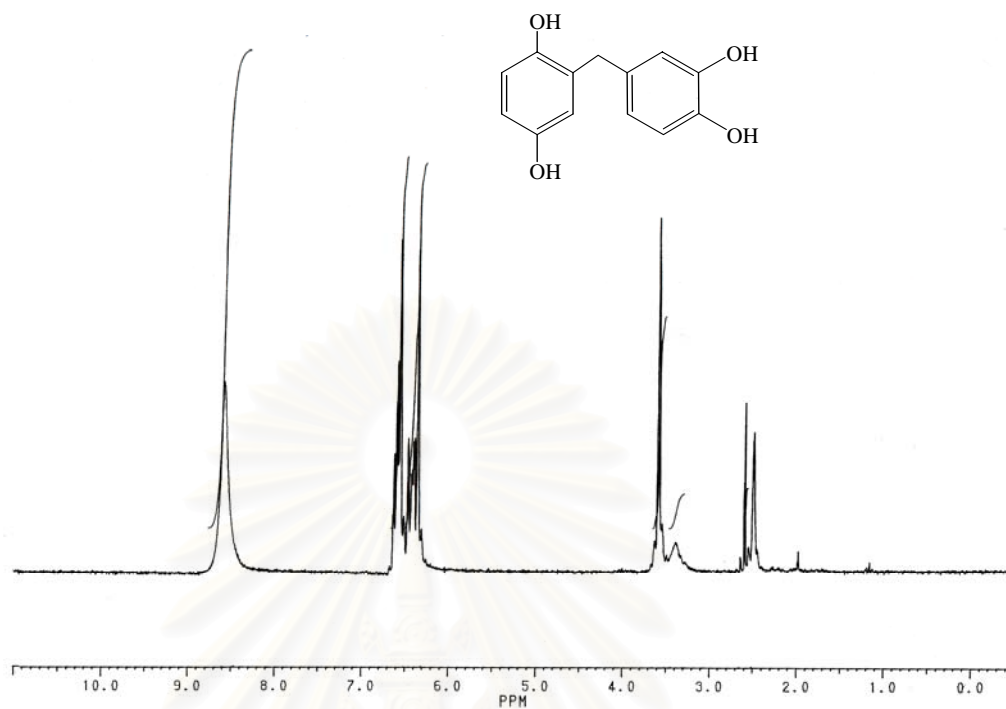
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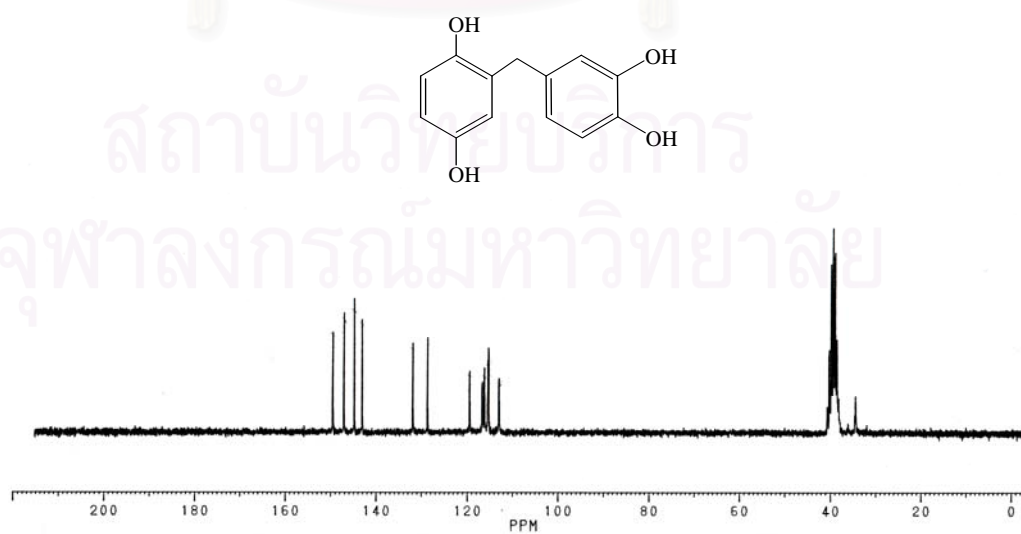
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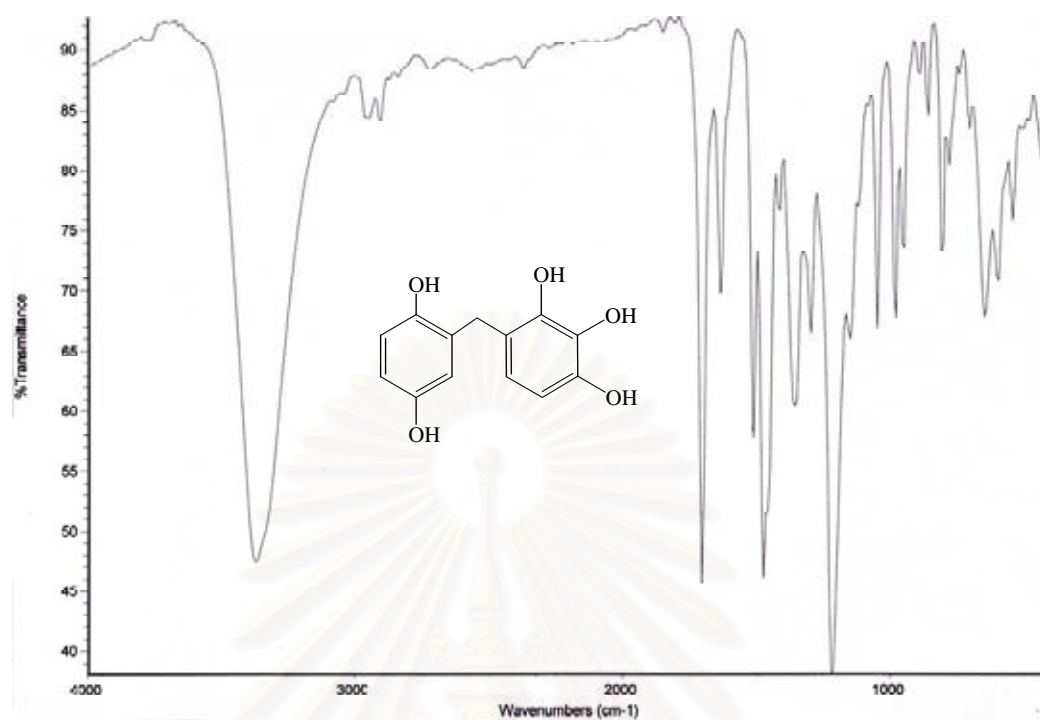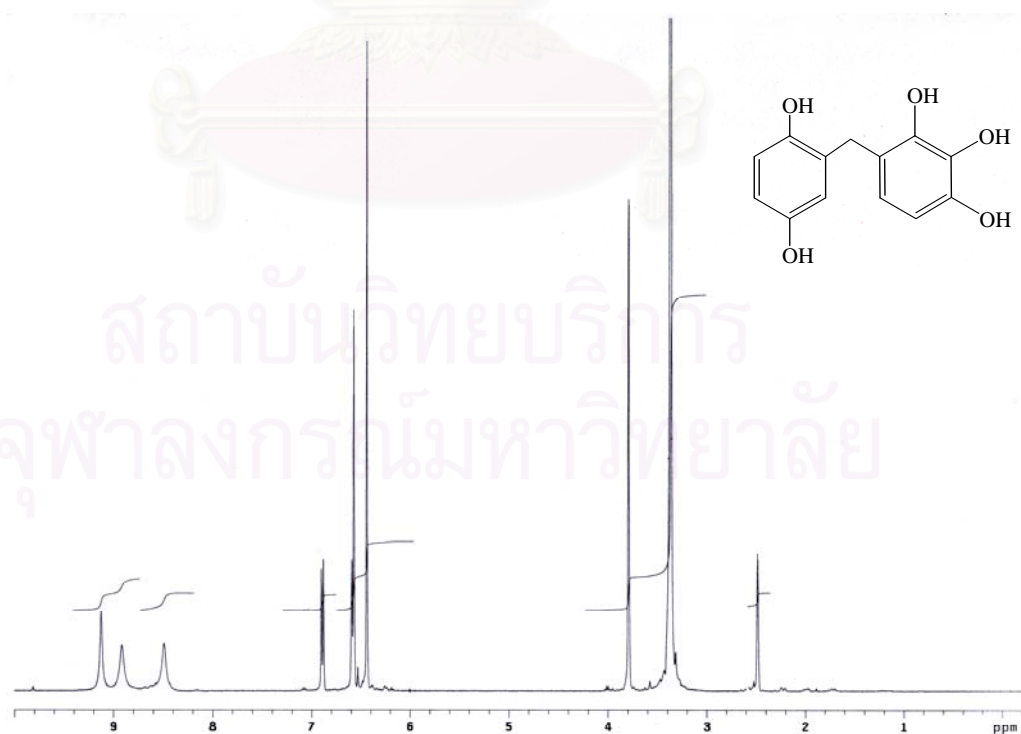
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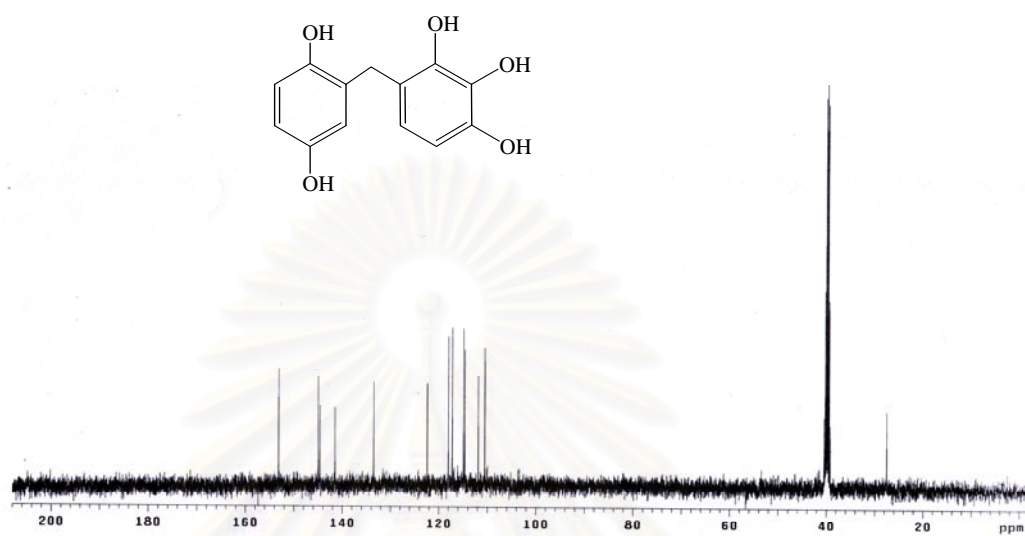

Figure A.8   The ^{1}H-NMR spectrum of **H7**

Figure A.9   The ^{13}C-NMR spectrum of **H7**
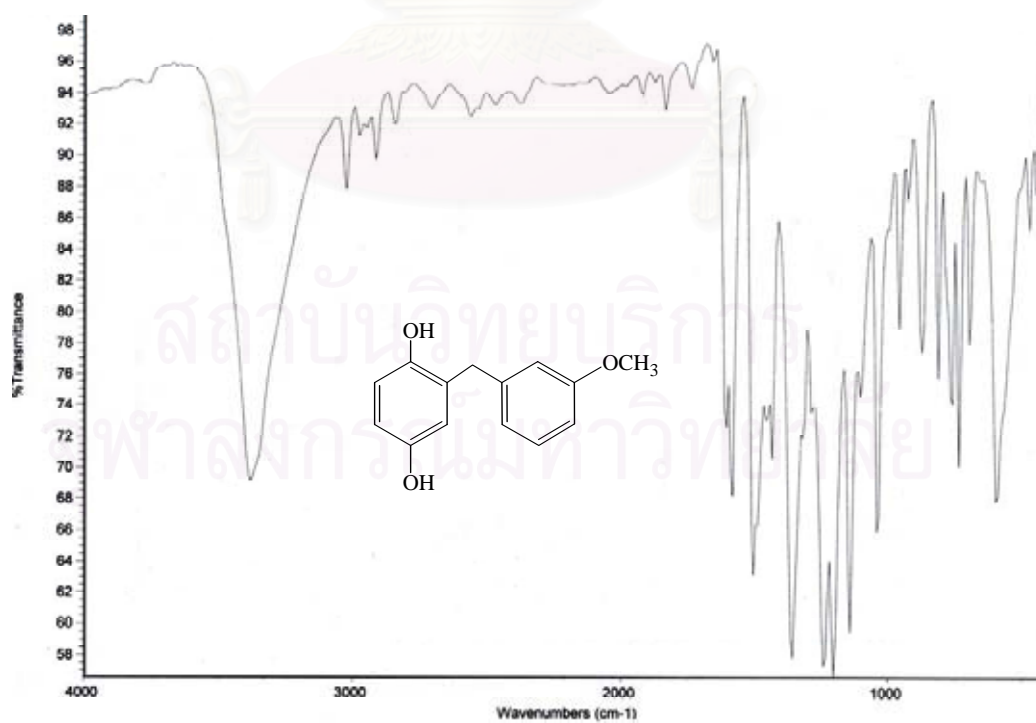
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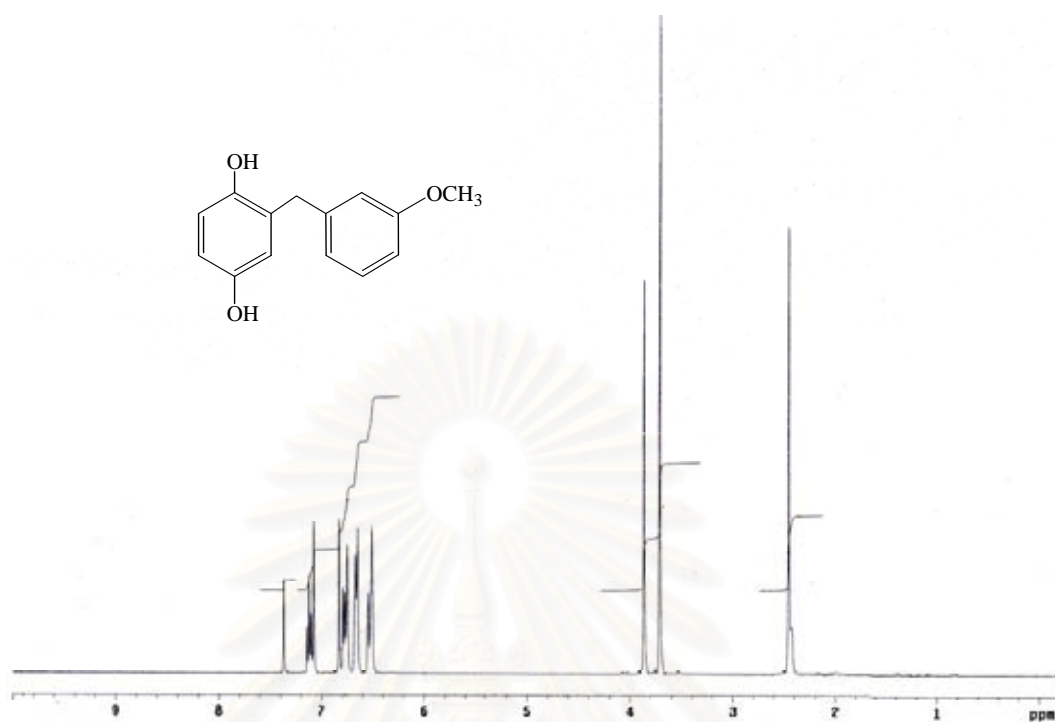
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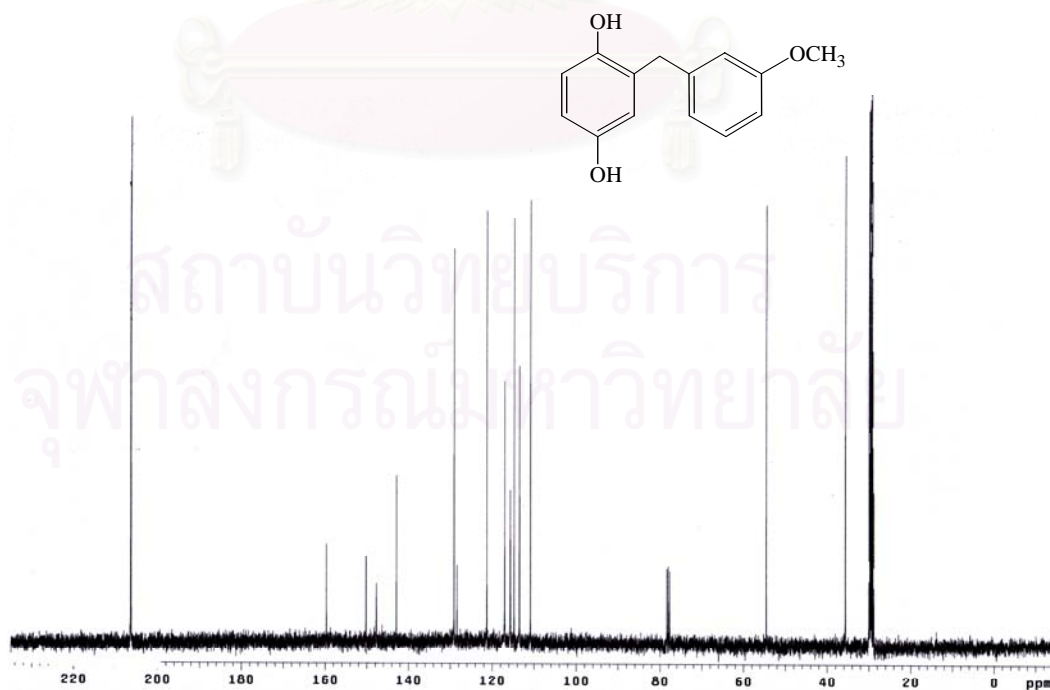
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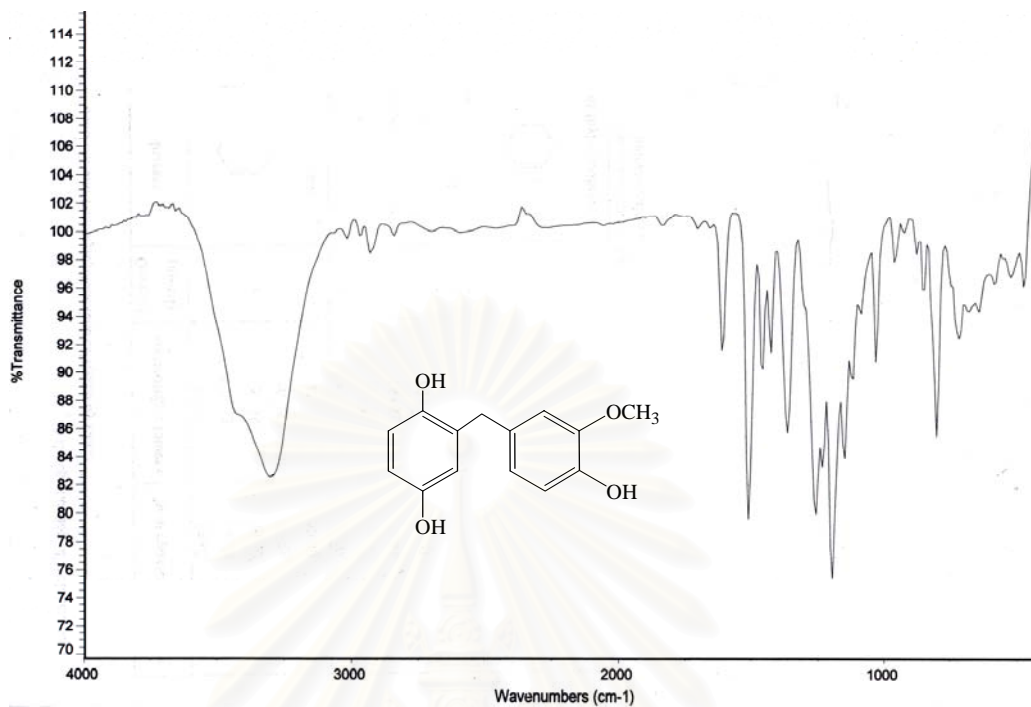
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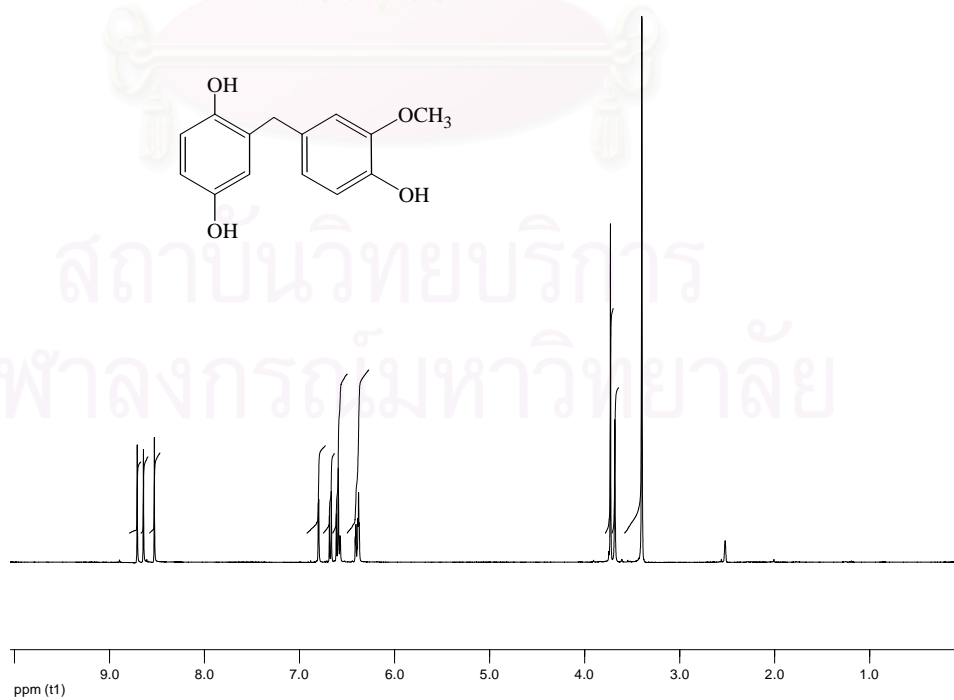
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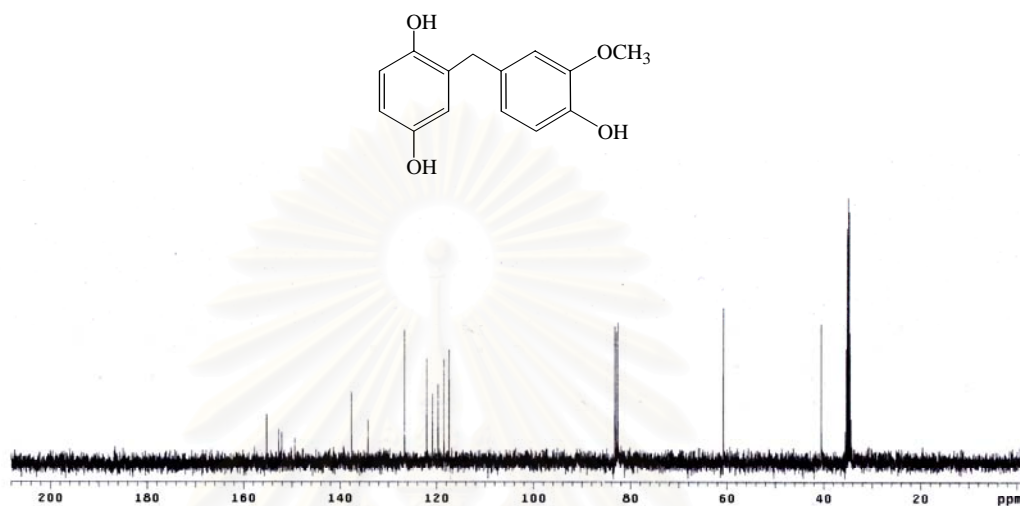
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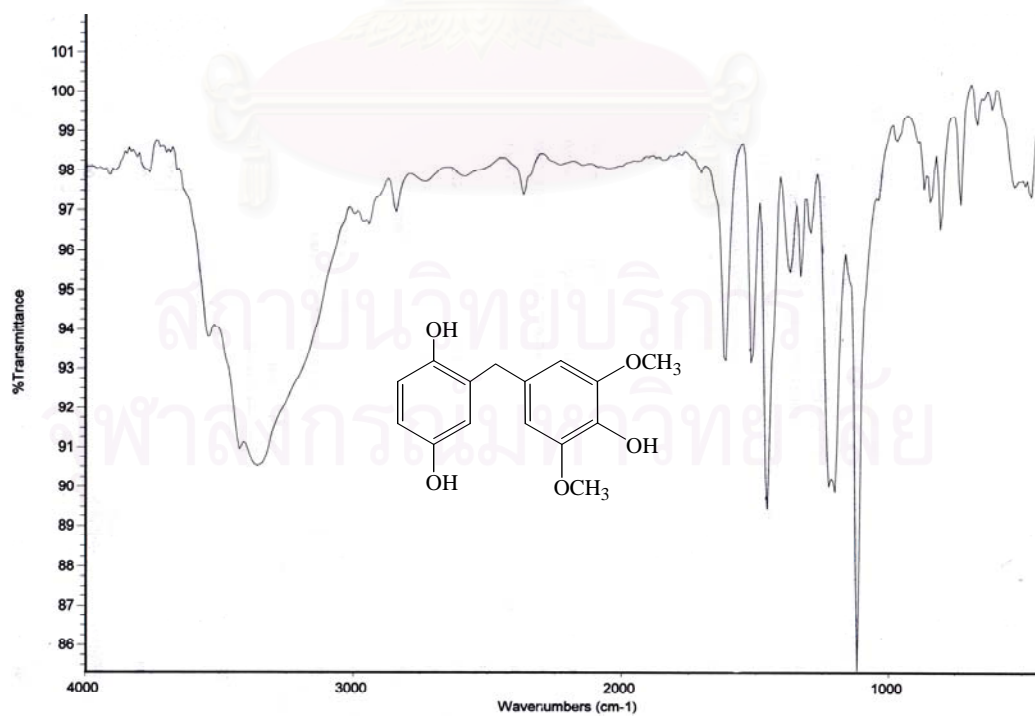
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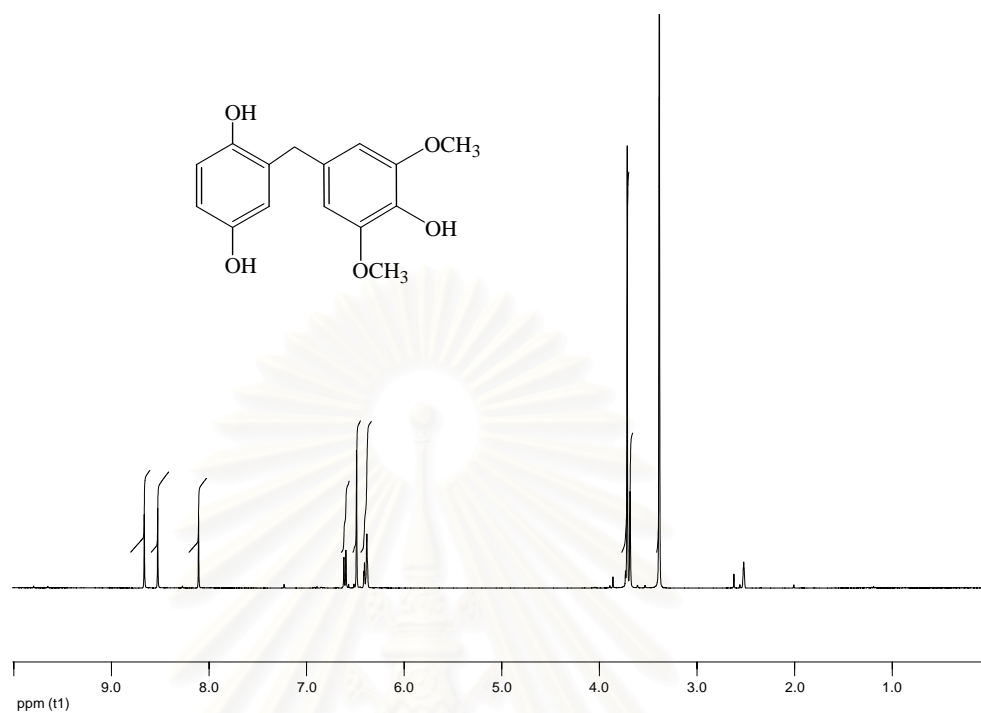
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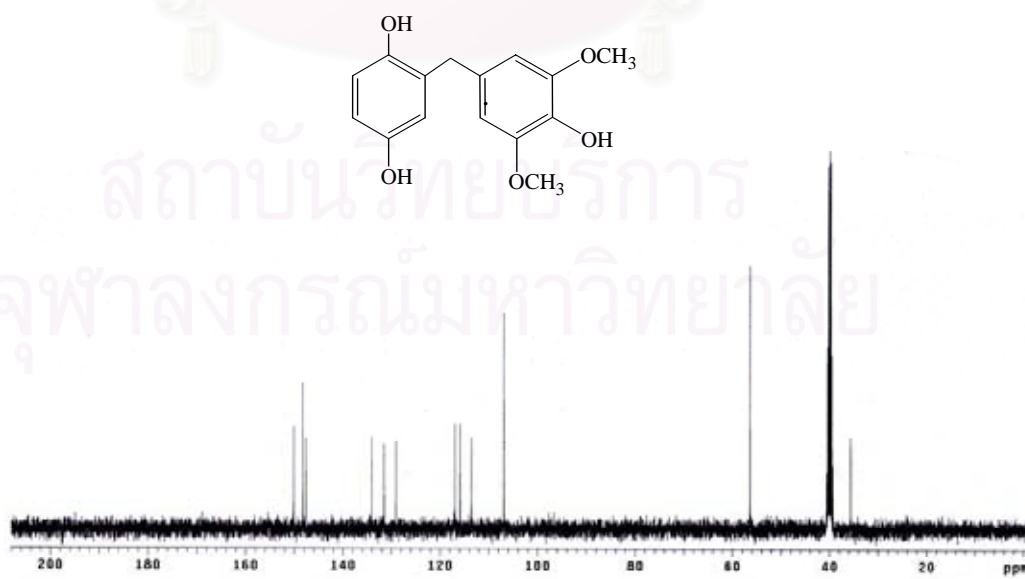
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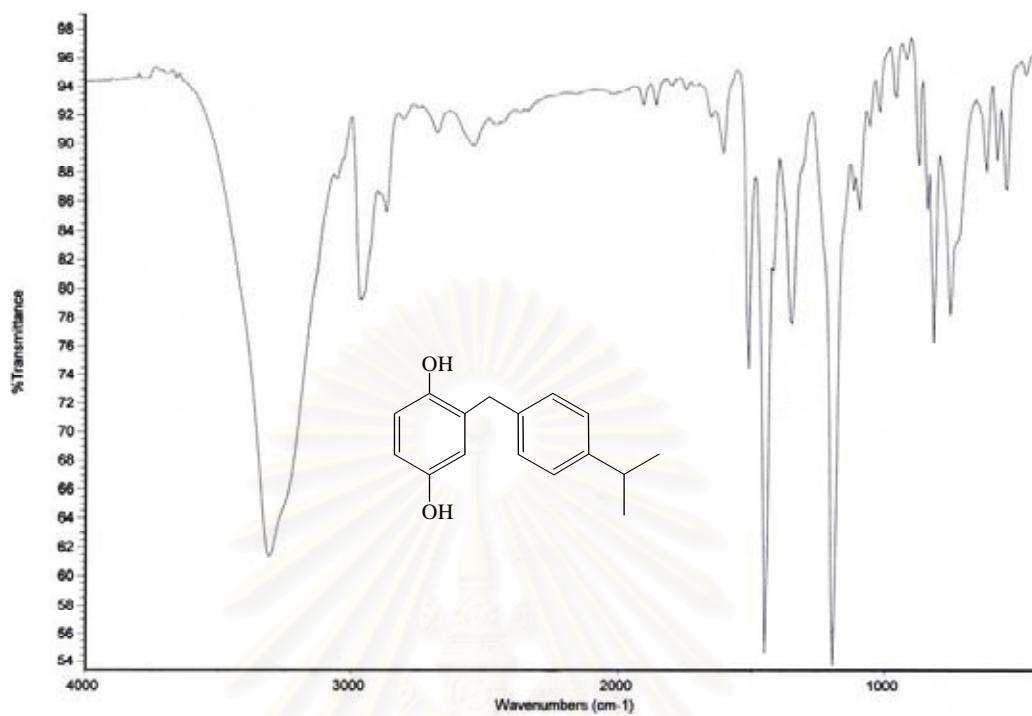
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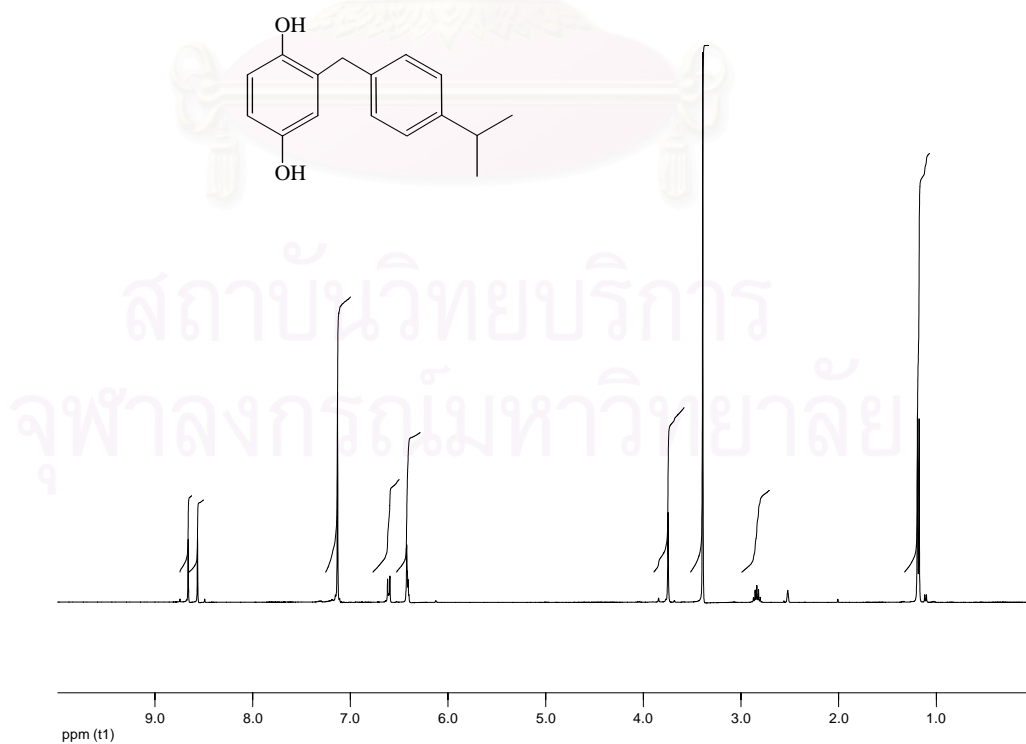
Figure A.20   The ¹H-NMR spectrum of **H13**
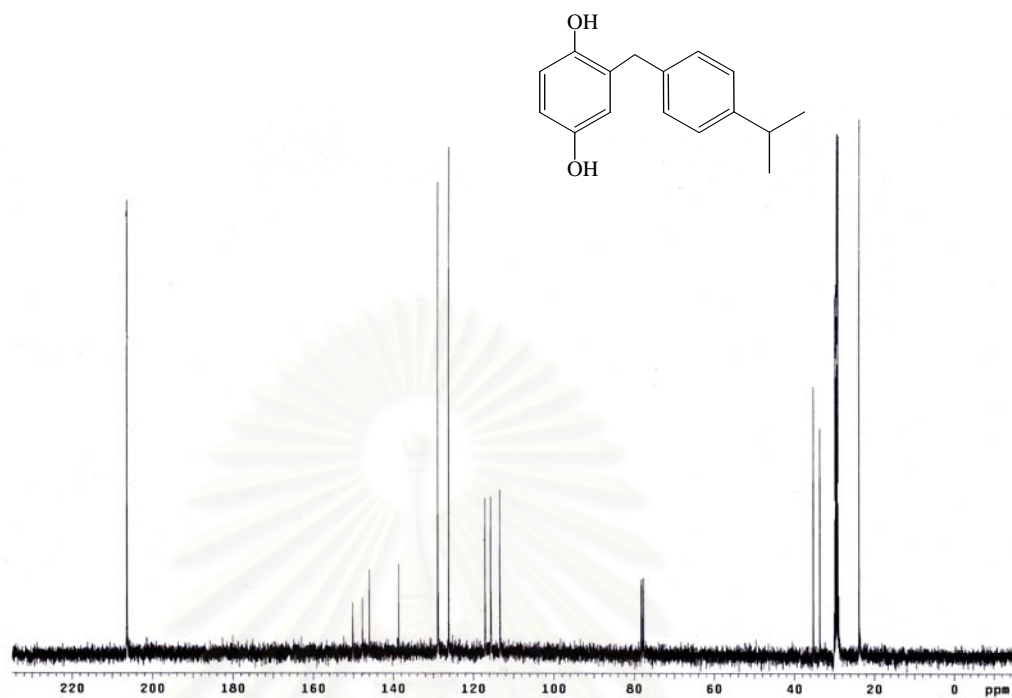
Figure A.21   The ^{13}C-NMR spectrum of **H13**
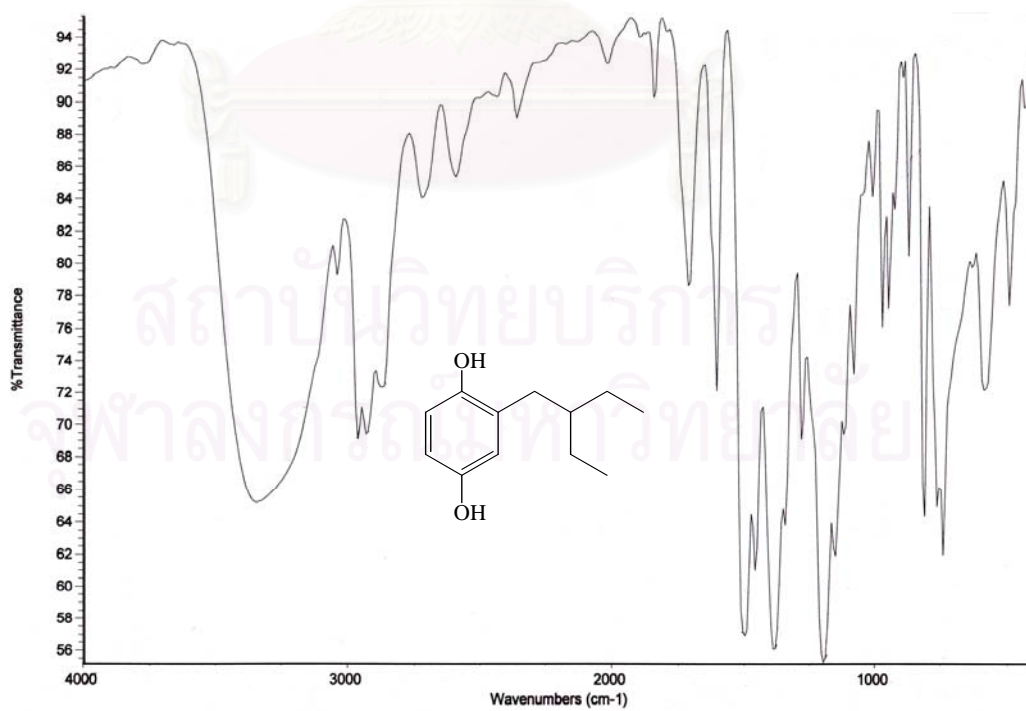

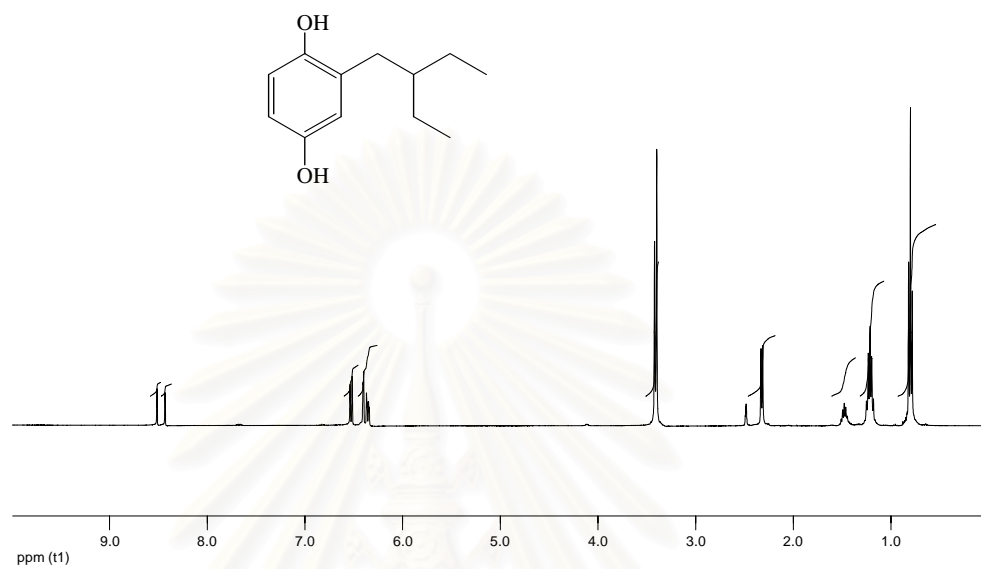**Figure A.22**   The IR spectrum of **H16**

Figure A.23   The ^{1}H-NMR spectrum of **H16**
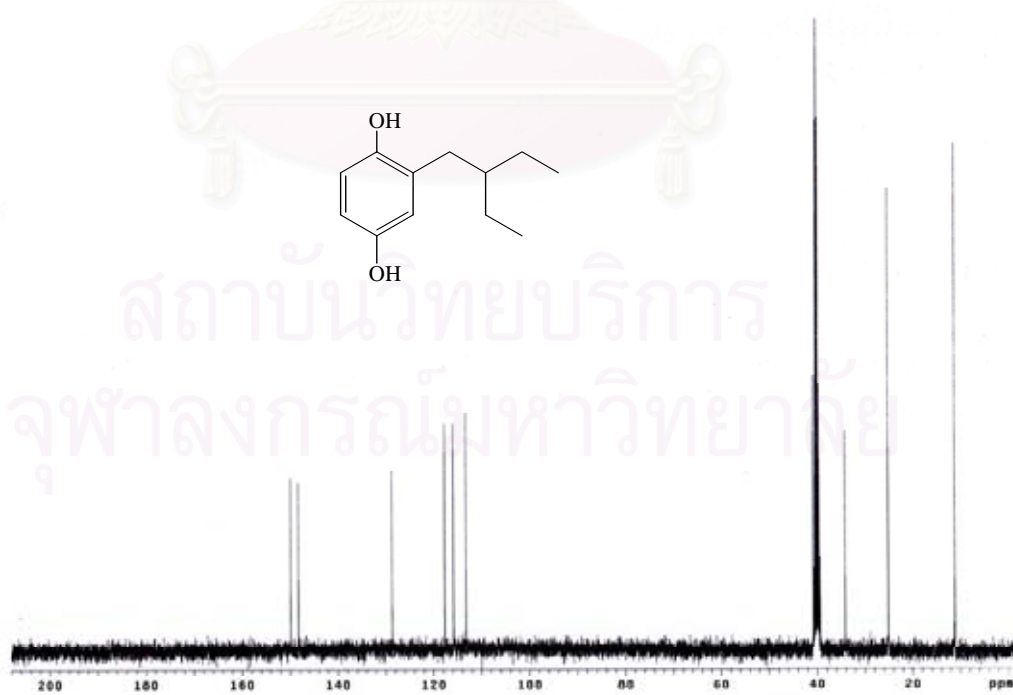
Figure A.24   The ^{13}C-NMR spectrum of **H16**
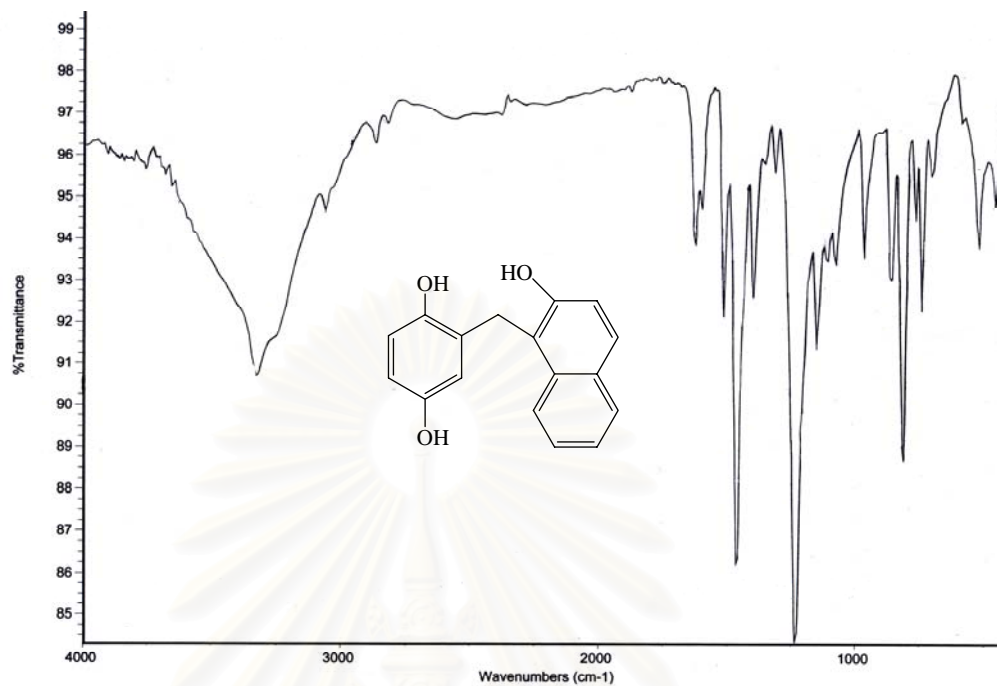
Figure A.25   The IR spectrum of **H20**
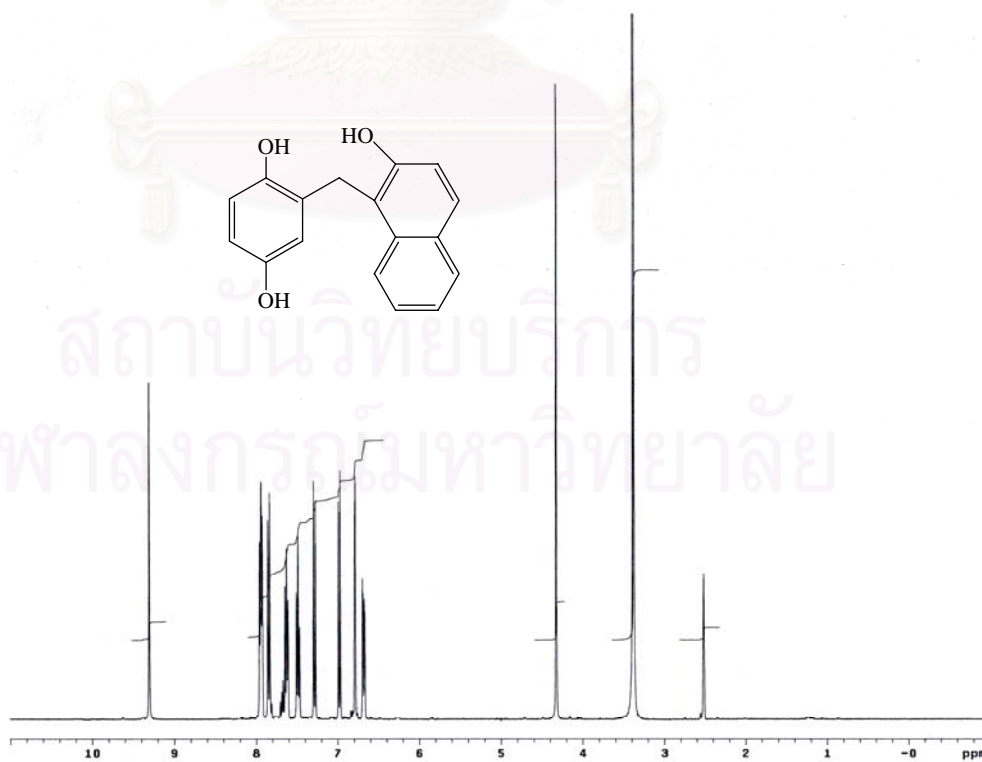
Figure A.26   The ^{1}H-NMR spectrum of **H20**
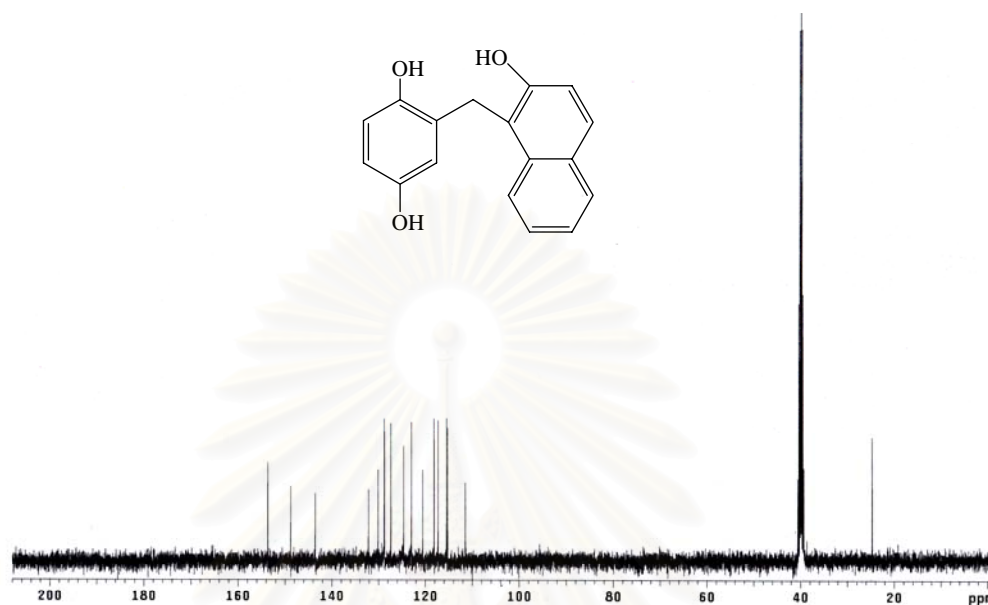
Figure A.27 The ^{13}C-NMR spectrum of **H20**
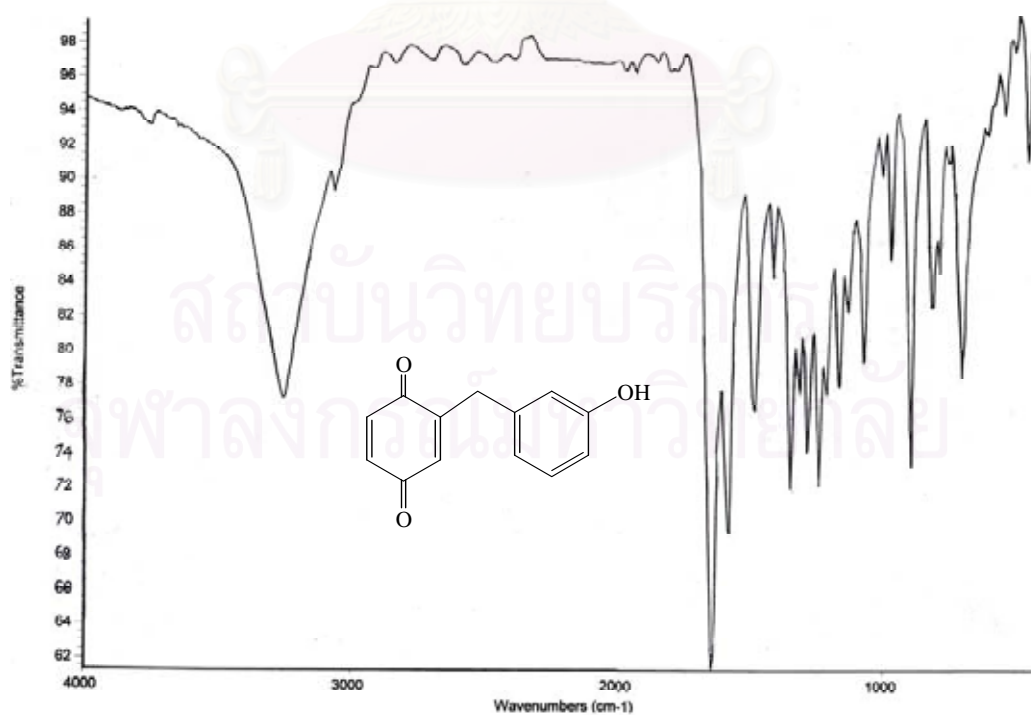
Figure A.28 The IR spectrum of **Q3**
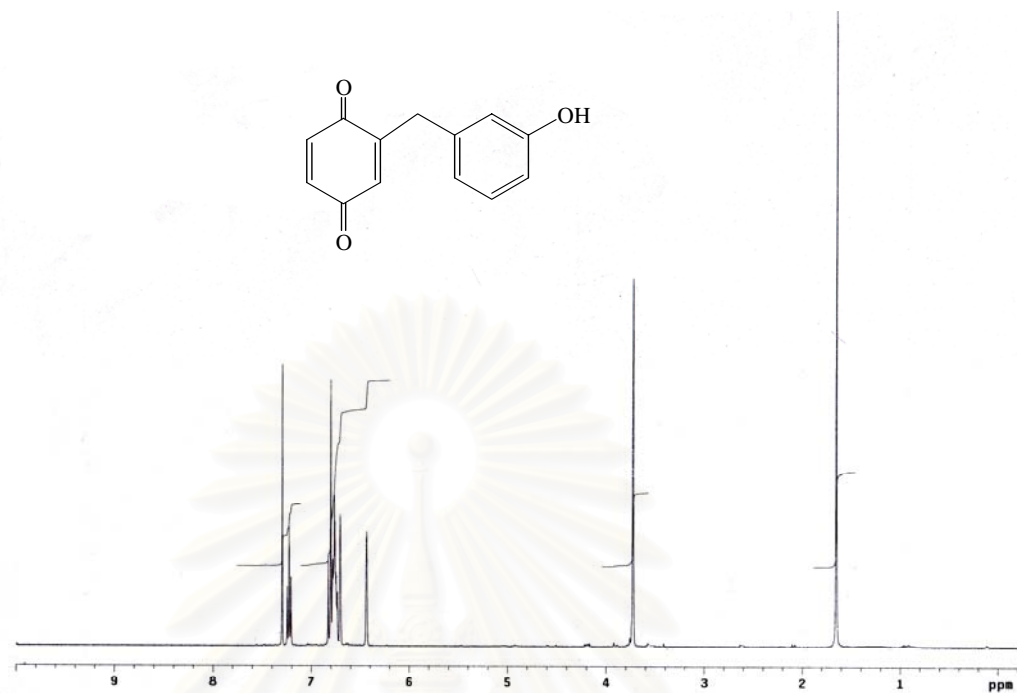
Figure A.29 The ^{1}H-NMR spectrum of **Q3**
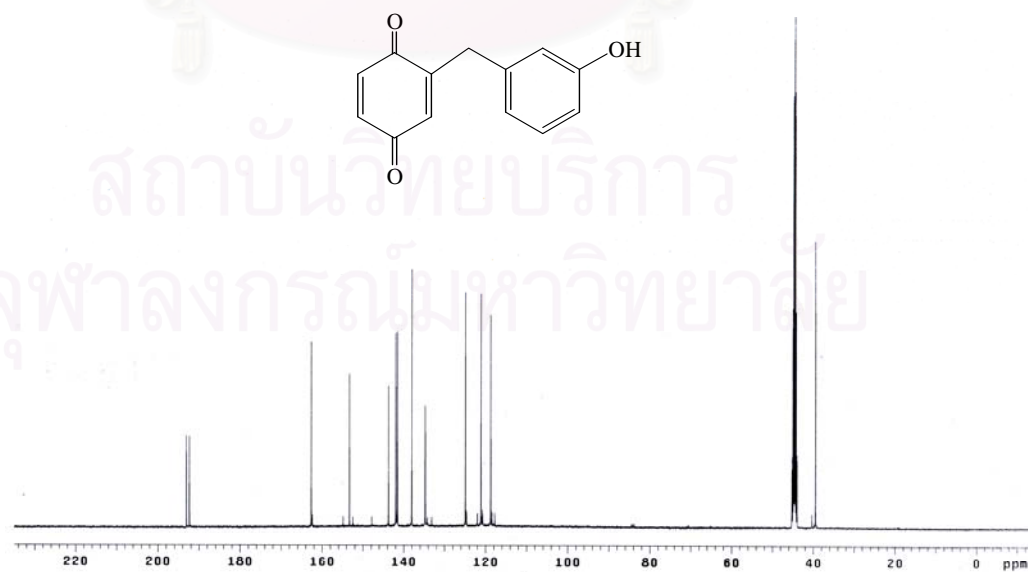
Figure A.30 The ^{13}C-NMR spectrum of **Q3**
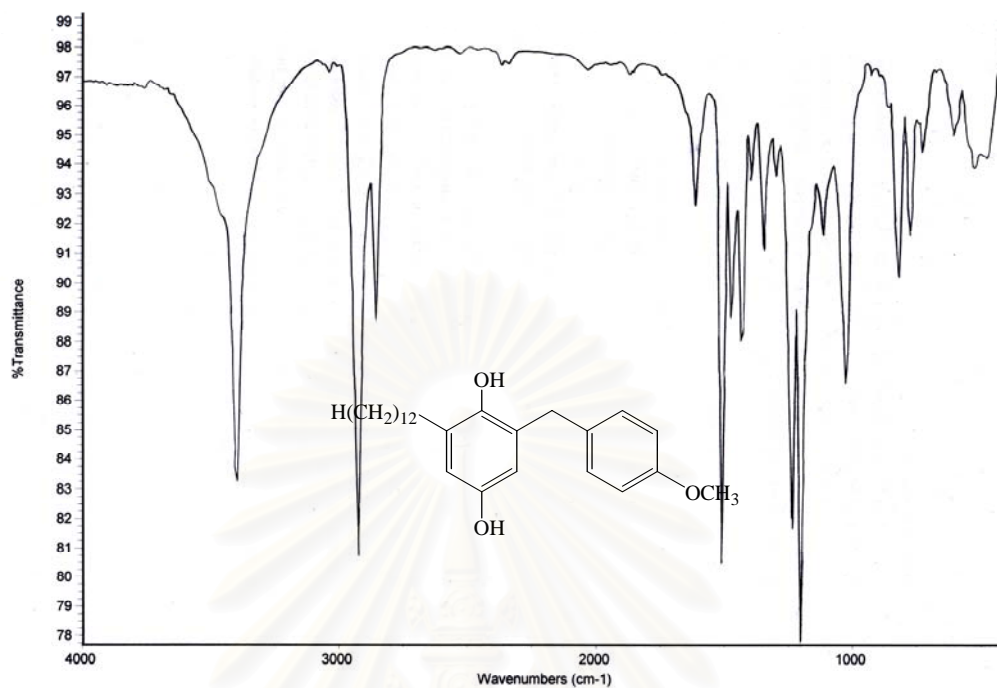
Figure A.31   The IR spectrum of **L2**
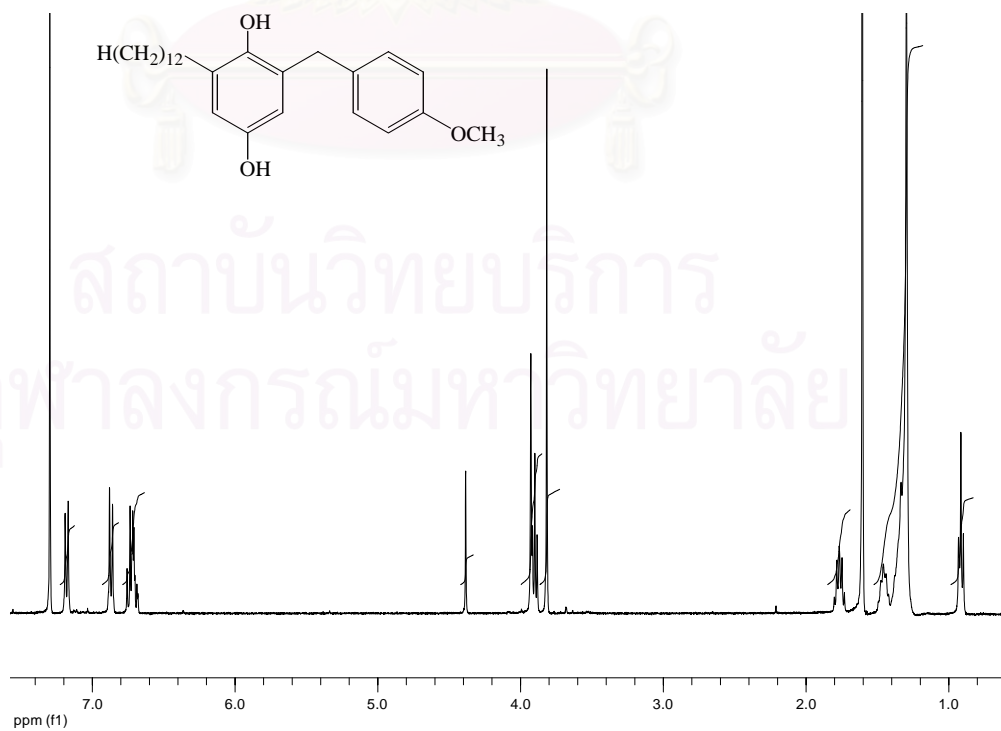
Figure A.32   The ^{1}H-NMR spectrum of **L2**
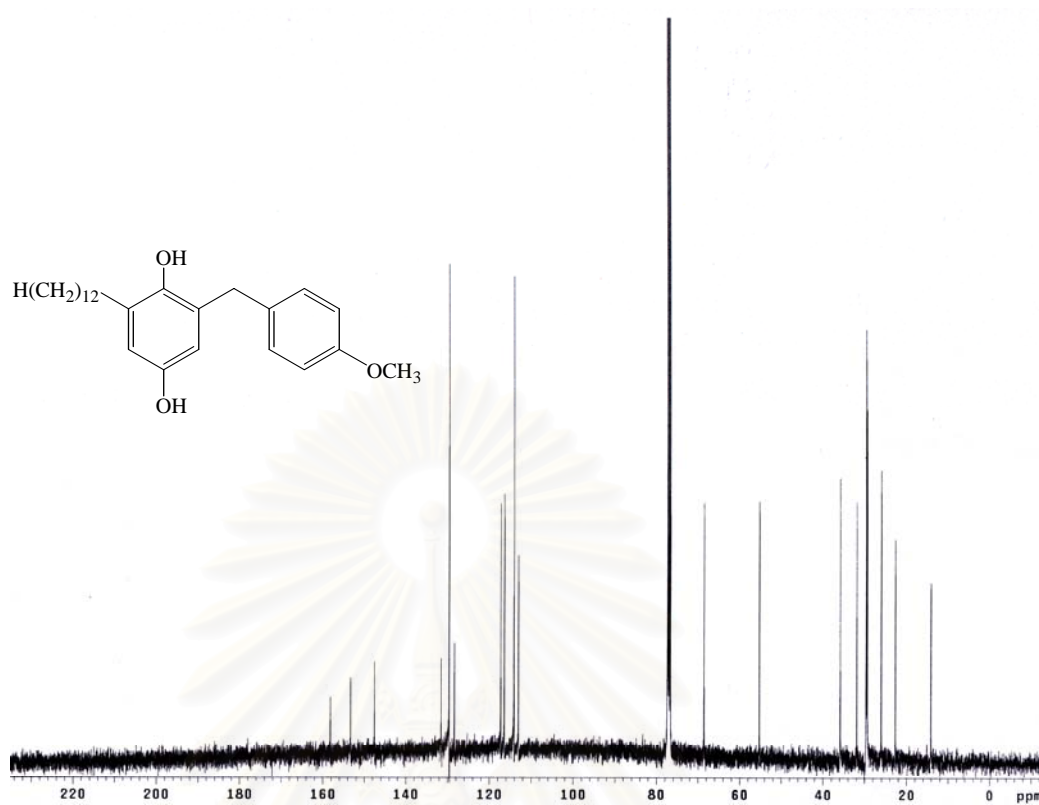
Figure A.33 The ^{13}C-NMR spectrum of **L2**
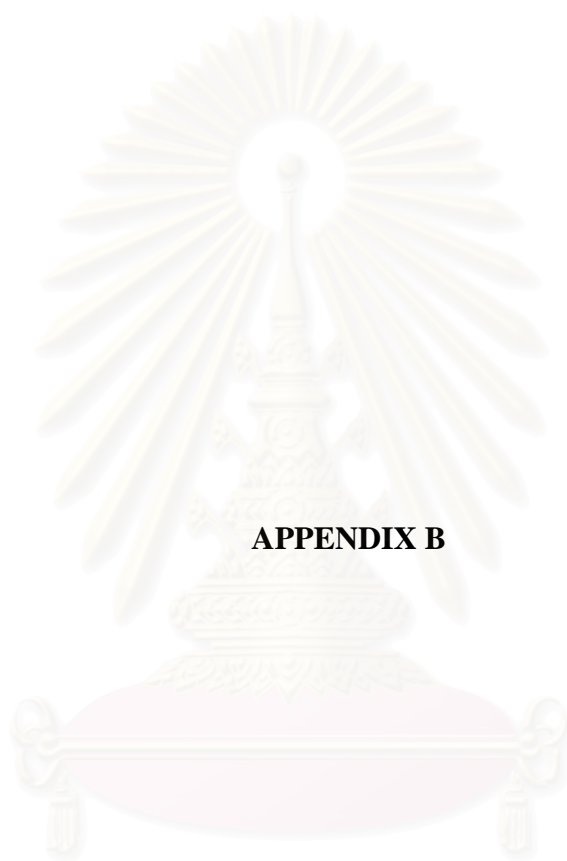
APPENDIX B

Table B.1 The % radical scavenging of the synthesized 2-alkylated hydroquinones
and related compounds

Compound	Concentration (mM)	%Radical scavenging	IC$_{50}$ (mM)
H1	1	90.52	0.13
	0.5	87.08	
	0.25	91.16	
	0.125	48.60	
	0.0625	22.55	
H2	1	86.01	0.18
	0.5	78.50	
	0.25	63.40	
	0.125	44.45	
	0.0625	25.24	
H3	1	91.19	0.13
	0.5	91.93	
	0.25	89.98	
	0.125	48.26	
	0.0625	21.41	
H4	1	89.74	0.13
	0.5	90.66	
	0.25	89.98	
	0.125	51.13	
	0.0625	23.23	
H5	1	78.59	0.22
	0.5	69.42	
	0.25	55.03	
	0.125	36.17	
	0.0625	20.17	

Table B.1 (continued)

Compound	Concentration (mM)	%Radical scavenging	IC_{50} (mM)
H6	1	91.32	< 0.06
	0.5	91.16	
	0.25	90.71	
	0.125	89.26	
	0.0625	76.86	
H7	1	91.94	< 0.06
	0.5	90.29	
	0.25	89.34	
	0.125	84.53	
	0.0625	44.06	
H8	1	90.26	0.11
	0.5	91.36	
	0.25	90.51	
	0.125	60.01	
	0.0625	28.77	
H9	1	90.49	0.13
	0.5	91.35	
	0.25	91.79	
	0.125	50.25	
	0.0625	22.13	
H10	1	91.45	0.13
	0.5	91.41	
	0.25	91.32	
	0.125	46.11	
	0.0625	21.60	
H11	1	89.09	0.10
	0.5	88.45	
	0.25	89.14	
	0.125	60.60	
	0.0625	36.44	

Table B.1 (continued)

Compound	Concentration (mM)	%Radical scavenging	IC$_{50}$ (mM)
H12	1	91.54	< 0.06
	0.5	92.04	
	0.25	92.16	
	0.125	91.30	
	0.0625	67.15	
H13	1	90.31	0.14
	0.5	90.85	
	0.25	84.69	
	0.125	41.50	
	0.0625	19.92	
H14	1	90.26	0.12
	0.5	90.41	
	0.25	90.70	
	0.125	51.63	
	0.0625	24.28	
H15	1	90.35	0.13
	0.5	90.83	
	0.25	91.20	
	0.125	48.37	
	0.0625	22.57	
H16	1	91.26	0.13
	0.5	91.45	
	0.25	91.31	
	0.125	48.42	
	0.0625	22.39	
H17	1	90.53	0.12
	0.5	91.01	
	0.25	90.94	
	0.125	53.65	
	0.0625	25.90	

Table B.1 (continued)

Compound	Concentration (mM)	%Radical scavenging	IC$_{50}$ (mM)
H18	1	91.37	0.12
	0.5	91.34	
	0.25	91.99	
	0.125	49.81	
	0.0625	25.45	
H19	1	90.38	0.12
	0.5	90.68	
	0.25	90.06	
	0.125	54.56	
	0.0625	25.61	
H20	1	84.90	0.18
	0.5	76.70	
	0.25	62.27	
	0.125	44.50	
	0.0625	27.98	
H21	1	92.24	0.14
	0.5	91.34	
	0.25	85.20	
	0.125	42.31	
	0.0625	22.39	
hydroquinone	1	94.75	0.13
	0.5	94.81	
	0.25	92.33	
	0.125	47.19	
	0.0625	17.82	
TBHQ	1	91.48	0.13
	0.5	91.54	
	0.25	85.35	
	0.125	42.65	
	0.0625	23.33	

Table B.1 (continued)

Compound	Concentration (mM)	%Radical scavenging	IC$_{50}$ (mM)
monoacetyl hydroquinone	-	-	no activity
Diacetyl hydroquinone	-	-	no activity

Table B.1 The Rotating Bomb Oxidation Test result of **H12**

Bomb Number: 5
User Name / ID:Administrator
Transducer ID:5
Sample ID: 1
Sample Name: s17
Bath Num: 2
Test Method: ASTMD2272
Stop Pressure (Psi): 25.4
Bomb Status: Reached End Point
Start Date/Time: 30/5/2548 11:23:02
Current Pressure (Psi): 67.2
Running Time (Min): 115.9
Max. Pressure (Psi): 173.49
End Point (Min): 55.071
Temperature (C): 147.39

End Point =55.071 Mins, Pressure =148.09
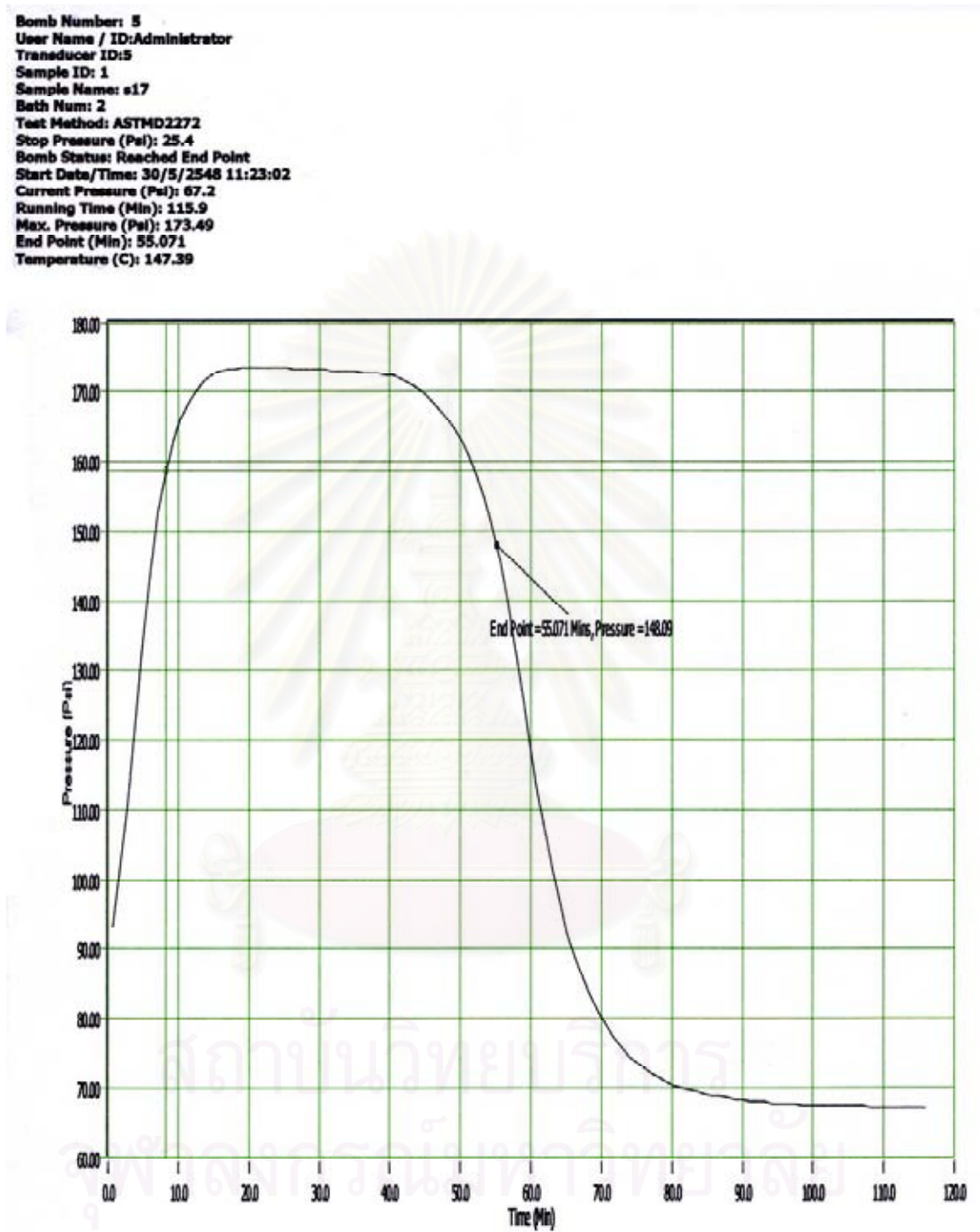
VITA

Miss Salinthip Prathuangsuksri was born on June 12, 1982 in Bangkok, Thailand. She graduated with Bachelor's Degree in Chemistry from Faculty of Science, Chulalongkorn University in 2002. She continued her study in Petrochemistry and Polymer Science Program, Faculty of Science, Chulalongkorn University in 2003 and completed in 2005.

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