# EFFECT OF PYROLYSIS CONDITIONS ON PYROLYTIC OF SCRAP TIRES UNDER REDUCED PRESSURE

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## ABSTRACT

A pyrolysis system was designed for the production of active carbon and other products from scrap tires. This system allows work under reduced pressure (vacuum).

The optimum conditions for the production of active carbon and pyrolytic oil were determined.

The optimum conditions were temperature $430^{\circ}C$,pressure 0.35 bar, and particle size 10mm at which the yield of active carbon and pyrolytic oil were 40.0 wt% and 58.5 wt% respectively.

The effect of experimental variables on the yields at active carbon and pyrolytic oil was studied using Box –Wilson technique of experimental design and useful relationships could be attained. The experimental data obtained by this design are successfully fitted a second order polynomial mathematical model.

**Keywords:** Scrap Tires, Pyrolysis

## INTRODUCTION

Tires are built to be tough and durable, the properties which ensure a safe ride and long service life make scrap tire disposal a difficult task. While scrap tires represent less than (2%) of total waste stream in industrialized countries, problems associated with scrap tire get a disproportionate amount of attention. The hazards most commonly posed by the unsafe disposal or scrap tires (diseases, carrying rodents, mosquitoes, also it caused a fire)[1,2].

About (85%) of scrap tires are automobile tires, the remainder being truck tires. Scrap tires can be managed as whole tire, a slit tire, a shredded or chipped tire, as ground or as crumb rubber prod net[3].

The general of scrap tires physical, chemical mechanical and other properties are given in the table (1)[2,4,5]. Many recycling processes[6-8] can be adopted for scrap tires such as fuel source, pyrolysis, depolymerization in asphalt and reclaiming. The use of scrap tires for fuel is the best alternative process for rinsing rubber as natural gas and fuel oil costs increases. Also the whole tires beneficially utilized as playground and athletic equipment, artificial reefs(9).

Utilization of cut tires include door mats, wheel chocks, rail road crossing mats manhole collar The cut tires also offer an excellent raw material for the production at many creature and marketable products ranging from neck tires to saddle bags(9).

Many authors(10-14) studied a vacuum pyrolysis which typically carried out at temperature of (480-520)°C and total pressure lower than [10kpa]. Vacuum pyrolysis of scrap tires has several advantages over other alternative tire recycling methods for application and safety properties also the total pyrolytic oil may be directly used as fuel or subjected to distillation(10). A research(15) developed a method that uses crumb rubber to filter wastewater, which can help ease the tire problem and clean up the environment at the same time. The study(16) was determined the technological and economic feasibility of the secondary separation process to gain as much of components from waste tires that converges to 100%. The production of adsorbents from pyrolysis of scrap tires as waste treatment process has attracted considerable attention because of the high carbon content (70-75 wt.%)(17).

**The aim** of the present work is the production of active carbons [A.C] and other useful products from the pyrolysis of scrap tires under vacuum pressure. The main approach is to study the effect of different operating condition on these products by applying Box-wilson techniques to reach the optimum operation – condition in pyrolysis process.

## EXPERIMENTAL

### Materials

Scrap tires coarse particle size with range (3-100 mm) , from general company of Najaf rubber / reclaim factory ,that will be sieved and classified with range (2-20 mm) under study for cotton type/ truck tire waste .

### Experimental program

The tubular reactor [1.25m, length and 0.03 m I.D stainless steel] and electrical furnace [R.S stock No.346] designed for experimental pyrolysis system the sealing of gas and connecting a vacuum pump at the outlet of the gas receiver post the water coiled condenser. The system is schematically shown in Fig.(1).

Scrap tire samples (30-45) gm of various particle size of 20cm height were introduced to the reactor. Reduced pressure was applied to the system (0.5-0.2) bar. Furnace was set to the required temperature of bed were recorded at each 15min. by digital thermometer [ELE model 2002]. Beyond 150°C a water vapour was seen at both condenser and trap. But brown liquid was appeared at 250C° in both cyclone and trap (11) (see Figure 1).The pyrolysis process was continued until the liquid in the condenser ceased. Also both oil and pyrolytic active carbon products were sent to weight and analysis.

Where both products of active carbon and pyrolytic oils were analyzed in the laboratory of chemical engineering department and ministry of industrial and metallurgy / Al – Majed center , also in laboratory of Baghdad university / service lab .

The experiments were designed according to central composite Rotatable design [CCRD] for three variables in scrap tires under reduced pressure $X_1$= temperature of pyroysis (400-460)ºC

$X_2$ =Vacuum pressure (0.2-0.5) bar

$X_3$ = Particle size for scrap tire samples (2-20) mm.

The relationship between the coded and real levels is listed in Table 2.

## RESULTS AND DISCUSSION

The PCB ( pyrolytic carbon black ) yields matches the concentration of virgin carbon black in the tires indicating that only a limited amount of carbonaceous deposits are produced on the carbon black surface during the pyrolysis[14], shown in the Fig.2. And the effect of both particle size and temperature on the yield of solid product is shown in Fig.(3), apparent that optimum amount of solid products appeared at (430)°C and (10)mm of particle size (41.27%), which gave nearest values of that results from CCRD method (40.752%)[18].

$$Y_{A.C}=40.79–2.03X_1-0.51X_2–1.49X_3–2.41X^2{}_1+1.08X^2{}_2 + 1.16X^2{}_3–1.39X_1X_1–2.76X_1X_3–1.06X_2X_3 \quad ----------------(1)$$

See Table (3) to show the statically analysis for this process.

**Vacuum pyrolytic oil**

Figure (4) indicate the effect of temperatures on the oils yield under optimum reduced pressure and various particle size which indicate that small particle size of scrap tire samples (2,6,and 10) mm yield is decreases with further increasing in temperatures (430-460,and 420°C) due to carding of pyrolytil in to gaseous products[19] .

Figure (5) indicate the effect of both temperatures and particles sizes on the amount of oils by vacuum pyrolysis .

yield of oil products by a three dimension graph, which show the optimum condition of temperature and particle size (430°C, 10mm) gives (59.27wt %) nearest to CCRD method (8.5wt %)[15].

$$YOIL=575+1.41X_1+0.33X_2+1.15X_3+2.13X^2{}_1-1.53X^2{}_2-1.63X^2{}_2 \quad -1.59x \quad 10\text{-}2X_1X_2+1.45\, X_1X^2{}_3-1.67X_2X_3 \quad \text{-------------(2)}$$

The statically analysis of this process is given in Table (3).

**Effect of vacuum pressure**

**Solid products:** The sharp decreases in the yield of active carbon is obtained with further increase in pressure for the large particle size of scrap tire samples, and have optimum yield of active carbon at (0.35) bar (40.75286wt%) for small particles (2 and 6 mm) due to the limited concentration of virgin carbon black, as shown in Fig.(6)[10,14].

**Oil products**: The oil products have sharply increased for particle size with pressure till optimum value (0.35) bar due to further cracking at these pyrolysis condition. But the yield almost becomes constant for large particle size samples at this vacuum pressure (0.35) bar shown in Fig.(7) due to limited concentration of virgin carbon black.

**Effect of particle size**

**Solid products:** Figure (8) indicate that same effect of temperature occurred on the yield of active carbon, which is reached at optimum condition (430°C, 10mm) (40.7528wt %) and constant amount of active carbon for small particle size (2 and 6) mm.

**Oil product:** Sharp increase occurs in the pyrolytic oil yield with increasing of particle size until reach optimum condition (430)°C , and 10mm of temperature and particle size then the oil yield is decrease for small pieces (2-10) mm the temperature range (400-430)°C and became constant due to cracking of pyrolytic oil in to gaseous products[19], as shown in Fig.(9).

## CONCLUSIONS

1-The optimum operation conditions, for active carbon and oil production from the pyrolysis of scrap tire, are temperature (430)°C, vacuum pressure (0.35) bar, particle size (10) mm under the optimum condition, the yields of active carbon and pyrolytic oil are (40.0wt %, 58.5wt%).

2-Aquantitative relationship between active carbon and oil production in the three variables (temperature, vacuum pressure, and particle size) pyrolysis process can be representing by a second order Polynomial model.

3-The temperature has a large effect on the amount of active carbon in case of small particle size (2, 6, and 10) mm, but vacuum pressure has slight effect on the amount of both active carbon and oil produced and the pyrolytis oil is increased with increasing temperature until reaching constant amount at (460)°C of (57.0 ± 0.75%).but the vacuum pressure have a large effect on large particle size ( 16, and 20 mm) , where gave the same optimum results of optimum temperature as vacuum pressure is 0.35 bar the optimum pyrolytic products were (57.0 % , and 40.0% ) .

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**Table (1)** general properties of scrap tires.

| Property | Shredded tire | Chipped | Crumb |
|---|---|---|---|
| Shape | Flat, irregularly | Uniform | Fine |
| Loose density ($Kg/m^3$) | 390 – 535 | 320 – 490 | |
| Compacted density($Kg/m^3$) | 650 – 840 | 570 – 730 | |
| Absorption values ( % %) | | 2 – 3.8 | |
| Specific gravity | | | 1.15 |
| Activity | Non-reactive | | |
| Chemical componen | Carbon black<br>Sulfur<br>Polymer<br>Oil<br>Paraffines<br>Pigments<br>Fabric<br>Bead | Carbon black<br>Sulfur<br>Polymer<br>Oil<br>Paraffines<br>Pigments<br>Fabric<br>Bead | Carbon black<br>Sulfur<br>Polymer<br>Oil<br>Paraffines<br>Pigments<br>Fabric<br>Bead |
| Internal friction angle($^o$) | | 19-26 | |
| Cohesion values (Kpa) | | 3.4-11.5 | |
| Permeability (cm/sec | | 1.5-15 | |
| Other properties | | | |
| Heating value (kJ/kg | 28,000-35,000 | 28,000-35,000 | 28,000-35,0000 |

**Table (2)** indicates the results of experimental planned according to central composite Rotatable design (CCRD ).

| Exp. No. | Coded Variables | | | Real Variables | | |
|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | Temperature ($^oC$) | Gas Flow ($m^3$/hr.) | Particle Size (mm) |
| 1 | -1 | -1 | -1 | 420 | 0.25 | 6 |
| 2 | 1 | -1 | -1 | 450 | 0.25 | 6 |
| 3 | -1 | -1 | -1 | 420 | 0.45 | 6 |
| 4 | 1 | 1 | -1 | 450 | 0.45 | 6 |
| 5 | -1 | -1 | 1 | 420 | 0.25 | 16 |
| 6 | 1 | -1 | 1 | 450 | 0.25 | 16 |
| 7 | -1 | 1 | 1 | 420 | 0.45 | 16 |
| 8 | 1 | 1 | 1 | 450 | 0.45 | 16 |
| 9 | -1.732 | 0 | 0 | 400 | 0.35 | 10 |
| 10 | 1.732 | 0 | 0 | 460 | 0.35 | 10 |
| 11 | 0 | -1.732 | 0 | 430 | 0.2 | 10 |
| 12 | 0 | 1.732 | 0 | 430 | 0.5 | 10 |
| 13 | 0 | 0 | -1.732 | 430 | 0.35 | 2 |
| 14 | 0 | 0 | 1.732 | 430 | 0.35 | 20 |
| 15 | 0 | 0 | 0 | 430 | 0.35 | 10 |

**Table (3)** the results of statical analysis for pyrolysis of scrap tires model of equitation 1&2

| Products | Correlation coefficient ( % ) | Estimate standard deviation of (y) | Average absolute error ( % ) |
|---|---|---|---|
| A. C | 95.65531 | 1.396758 | 1.739978 |
| Oils | 96.32013 | 1.277666 | 1.039282 |

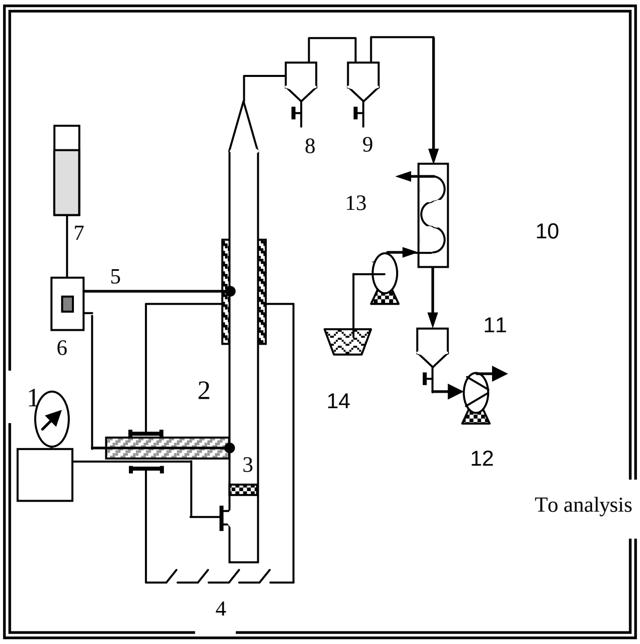


**Fig.(1)** Schematic experimental apparatus for pyrolysis unit under reduced pressure:1- vacuum gauge, 2- stainless steel reactor, 3- gas distributor, 4- electrical furnace, 5- thermocouples ( k-type ), 6- selector switch, 7- digital thermometer, 8- trap, 9- trap, 10- condenser, 11- trap, 12- vacuum pump, 13- pump 14- water tank

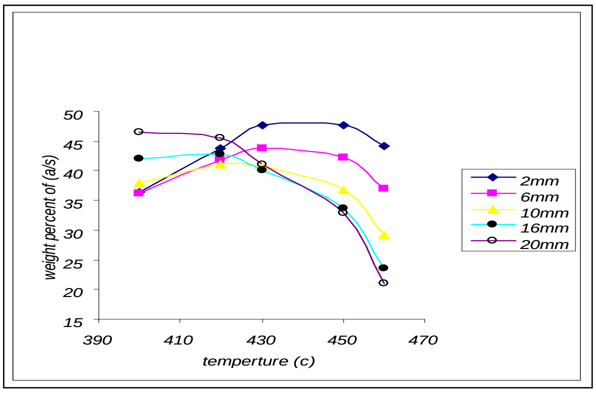


**Fig. (2)** Effect of temperatures on the amount of active carbon from vacuum pyrolysis , P= 0.35 bar .

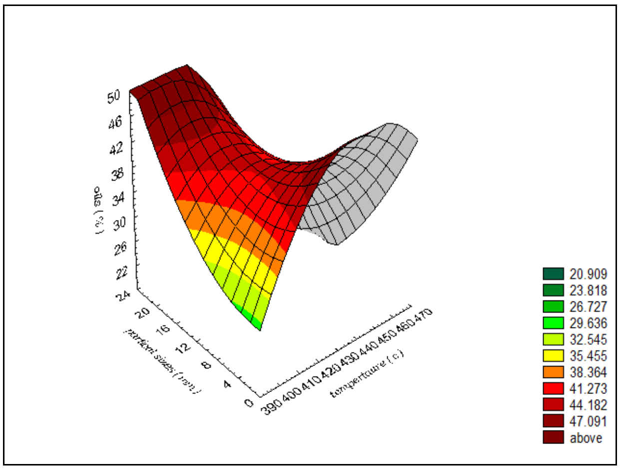


**Fig. (3)** Effect of both temperature and particle size on the amount of active carbon by vacuum pyrolysis

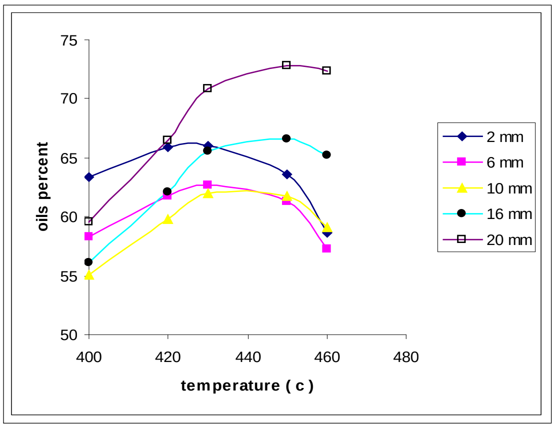


**Fig. (4)** Effect of temperature on the amount of oils from vacuum pyrolysis , P=o.35 bar

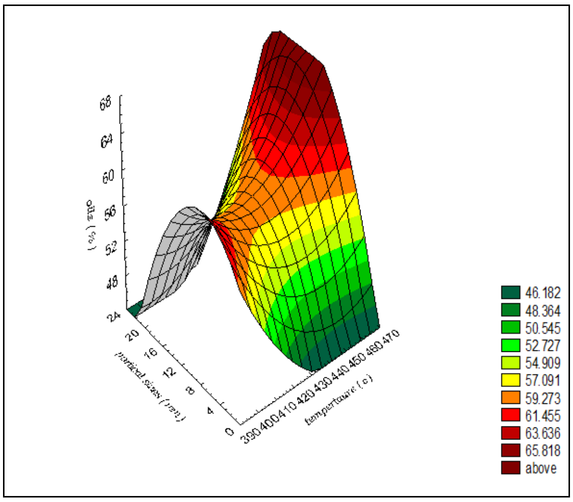


**Fig. (5)** Effect of both temperature and particle size on the amount of oils by vacuum pyrolysis .

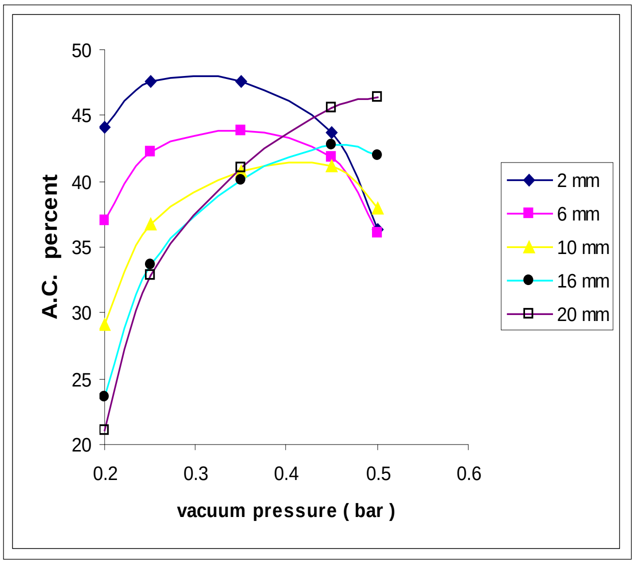


**Fig. (6)** Effect of vacuum pressure on the amount of active carbon from vacuum prolysis , T=350ºC

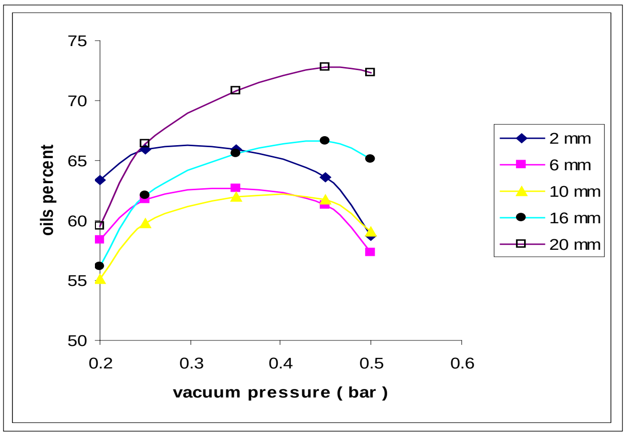


**Fig. (7)** Effect of vacuum pressure on the amount of oils by vacuum pyrolysis ,T=350 ºC.

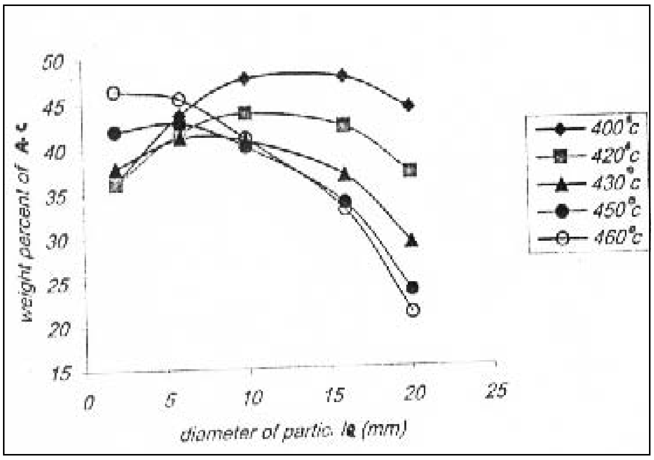


**Fig. ( 8)** Effect of particle size on the amount of active carbon Produced from vacuum pyrolysis

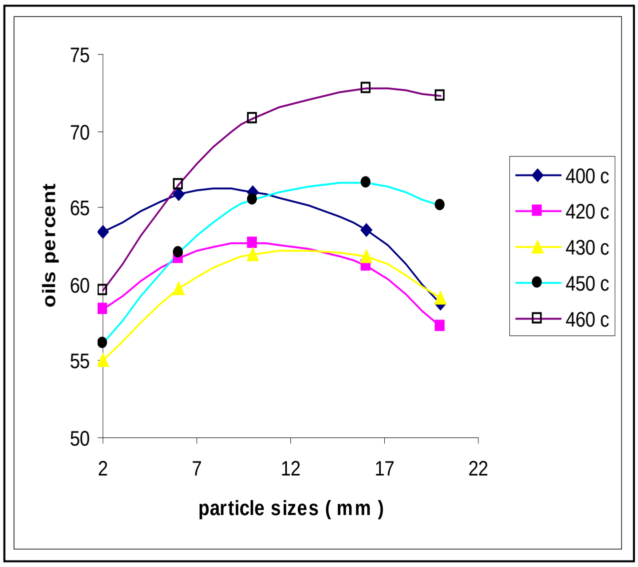


**Fig. (9)** Effect of particle size on the amount of oils from vacuum pyrolysis.

# دراسة السحق الحراري لمخلفات الاطارات، والظروف المثلى تحت الضغط الفراغي

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الخلاصة:

في هذا البحث تم تصميم منظومة تكسير متكاملة لانتاج الفحم المنشط ومنتجات اخرى من نفايات الاطارات المستهلكه وهذه المنظومه تعمل تحت جو مفرغ باستخدام فاكيوم .

ان المنظومة تعمل بشكل مثالي عند درجة حرارة 350مْ وضغط تفريغ مقداره 0.35 بار وحجم حبيبي لهذه النفايات (الاطارات المستهلكه ) 10ملم وتحت هذه الظروف المثاليه كانت المنتجات المثلى هي فحم منشط 40 وزنا% وزيوت تكسير قيمه مقدارها 58.5%.

ان تاثير المتغيرات التجريبيه على الحصيله لكل من الفحم المنشط وزيوت التكسير ثم دراسته باستخدام تقنية بوكس- ولسن لتصميم التجارب حيث تم الحصول على علاقة ذات فائدة عملية ونظرية ويمكن اعتمادها وتم الحصول على النتائج العمليه لهذا التصميم وبنجاح مطابق الى الموديل الرياضي ذو الدوال المتعدده من الدرجة الثانية وبنسبة خطا لاتزيد عن 1% ومعامل انطباق يصل الى 99.9% .