

# Recycled Medical Cotton Waste Modified via Torrefaction to be Used as an Enhanced Material for Energy Production

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*Abstract:* - Cotton is a wide known material since 6000 BC which now has its stock market. This material has a wide range of use and a huge annual production which explains why huge amounts of cotton waste and medical cotton waste exist. These amounts can be treated and become a considerable source of energy, instead of treated as common waste following the same procedures. The purpose of this study is to discover whether cotton is an efficient material for energy purposes and then to see in what conditions its gross heat of combustion can be maximized. More specifically we used a blast furnace in order to achieve torrefaction. The conditions applied were a non-isothermal heating up to 340°C for 20-50 minutes with 2.5 min step. The investigations of how pretreatment conditions, affected cottons gross heat of combustion happened in a calorimeter. The diagrams show analytically the dependence between time and temperature with gross heat of combustion.

*Key-Words:* - cotton, torrefaction, medical waste, gross heat of combustion, recycling, severity factor.

## 1 Introduction

Cotton is one of the most ancient natural materials known to earth. Mexicans first of all, started using it around 5800 BC.; Greeks and Arabs at 300 BC. Samson Gamgee was the creator of Gamgee Tissue which made its first appearance in the medical and cosmetic sector around 1880, an absorbent cotton wool and gauze surgical dressing [1]. Cotton has a huge annual production. In 2016 this production is estimated at the amount of 106.7 million 480-lb. bales [2]. As a normal result, huge production creates great amounts of cotton waste. Cotton waste exists in two forms, post industrial waste and post-consumer waste. These two types of cotton consist the whole waste volume. Cotton is almost entirely made of cellulose and this makes cotton recycling a matter of interest.

Recycling cotton is an issue that has occupied science through years. Recycling mainly refers to textile production (post industrial waste) and reused textiles (post-consumer waste). The post-consumer cotton waste includes also the medical cotton waste. This fraction of medical waste can also be recycled by being a source of biogas recovery [3]. Another approach is the use of this fraction as a material for biogas production [4]. With the suitable pretreatment it can also be used as a dye remover from aqueous solutions [5, 6]. Each

recycling method has the same purpose but a different effect to cotton waste.

Medical cotton waste is considered infectious and hazardous due to its usage like all kinds of medical waste. Infected blood and chemicals are attached to it [7]. Generally medical wastes get burned into incinerators. This method is the most common and most efficient. It reduces the waste volume up to 90% and it can treat all kinds of medical waste. Its significant problem is the dioxin, furans and mercury emissions produced during the procedure [8, 9]. There are many treatment methods acceptable and approved by global organizations. The majority of them include sterilization [10], autoclave waste treatment [11], pyrolysis, gasification, plasma treatment [12]. Sterilization process can be achieved in a temperature of 134°C for 18 minutes and this is how surgical tools are sterilized generally [13]. Such method is used for sterilizing medical waste with similar temperatures applied.

The purpose of this study is to examine the feasibility of torrefying cotton in order to increase its thermal energy and use it as a heating material or as a supplementary material in energy production. This is a recycling procedure that will decrease the cotton waste volume and provide extra energy. This procedure sterilizes cotton simultaneously which

make it harmless for people. Measurements were made on both untreated and torrefied cotton. The two varied process parameters that were chosen for the experiment were time and temperature. Each experiment had different reaction time in the same heating curve, thus, different temperature. The reaction time was 20, 25, 30, 35, 40, 45, 50 minutes.

Torrefaction kinetics has been developed through years. A distributed activation energy model based on Avrami-Erofeev model has been used to reveal the torrefaction kinetics by Wang et al [14]. Doddapaneni et al [15] have used a combination of Arrhenius law with Coats and Redfern equation for the same purpose. Kinetics has been also simulated through a four-pseudo-component model [16]. Isothermal and non-isothermal torrefaction has been as well correlated with severity factor in order to examine its kinetics by Kim et al [17].

## 2 Materials and Methods

### 2.1 Material Development

A Greek medical consumables supplier provided the Cotton to the laboratory. It was manually cut into small pieces. This fraction is preferred because this way cottons' homogeneity can be achieved when the torrefaction procedure is over. Cottons' moisture was 5% measured via oven. The heating conditions that applied in cottons' moisture measurement were 110°C for 24 h in the oven

### 2.2 Torrefaction process

The torrefaction method applied to treat cotton occurred in a blast furnace. Cotton was inserted in a weighted porcelain capsule and placed in the blast furnace. Blast furnace was in room temperature. The heat increase curve was from 23°C up to 340°C. Each experiment had different reaction time. The time was increased by 5 minutes from 20 minutes to 50 minutes (20, 25, 30, 35, 40, 45, 50 minutes). There wasn't preheating time. When torrefaction process was over, the porcelain capsule was removed immediately from the blast furnace. It was put in a dryer for 15 minutes. The porcelain capsule was weighted in order to measure the tare. Cotton has taken by hand and put in a weighted zip-lock bag for 24 hours. After 24 hours torrefied cottons' moisture was measured in the oven and the result was 3%. The heating conditions that applied in cottons' moisture measurement were 110°C for 24 h in the oven.

### 2.3 Calorimeter usage

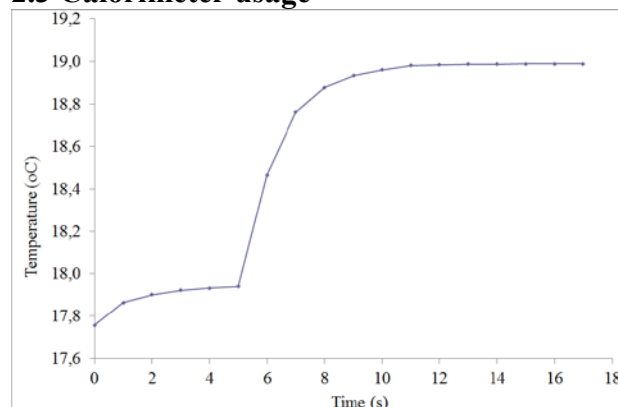


Fig.1: Temperature profile vs. time during the measurement of the gross heat of combustion.

A Parr 1341 Plain Jacket Calorimeter was used to take the necessary measurements. 0.5 g of cotton was put in the combustion vessel. The combustion vessel was charged with oxygen to 25 atmospheres. The calorimeter bucket was filled with 2000 mL of distilled water. The bucket was attached in the calorimeter and then the combustion vessel was put in the bucket. The two ignition lead wires were pushed into the terminal sockets on the bombs' head. The cover was set on the jacket and the stirrer was turned manually to ensure that runs freely. If it turns normally then the drive belt is slipped onto the pulleys and the motor is started. The Temperature indications were taken via the 6775 Parr Digital Thermometer each minute for 5 minutes in order to achieve equilibrium into the calorimeter. At the start of the sixth minute the ignition button was pushed and temp measurements were taken each minute until the temperature was stable again. The rise of the temperature will be rapid during the first minutes and slow when we get close to the equilibrium. The diagram below shows how the temperature is affected from the stages explained above.

In Fig 1 temperature curve as affected in each stage of the gross heat of combustion measurement procedure inside the calorimeter is shown.

## 3 Results and Discussion

The kinetics of gross heat combustion of untreated and torrefied cotton has been extensively studied using ISO 1716:2010 [18]. The widely used gross heat of combustion equation is shown below,

$$H_g = \frac{tW - e_1 - e_2 - e_3}{m} \quad (1)$$

where  $H_g$  represents the gross heat of combustion.  $m$  stands for mass of sample in grams.  $e_1$  refers to correction in calories for heat of formation of nitric acid,  $e_2$  to correction in calories for heat of formation of sulfuric acid and  $e_3$  to correction in calories or heat of combustion of fuse wire. Both  $e_1$  and  $e_2$  are equal to zero since we use neither nitric acid nor sulfuric acid.  $W$  is the energy equivalent of the calorimeter, determined under standardization.  $t$  is the net corrected temperature rise. The equations below give more information about these variables,

$$t = t_c - t_a - r_1(b - a) - r_2(c - b) \quad (2)$$

$$e_3 = l_f \cdot x_{2,3} \quad (3)$$

$$W = 2426 \text{ cal} / ^\circ\text{C} \quad (4)$$

Where  $a$  stands for time of firing,  $b$  for time when the temperature reaches 60% of the total rise and  $c$  for time at the beginning of period in which the rate of temperature change is constant.  $t_a$  represents temperature at firing time and  $t_c$  temperature at time  $c$ .  $r_1$  is the rate at which the temperature was rising until firing and  $r_2$  the rate at which the temperature rising during the 5-min period after the time  $c$ .  $l_f$  is the size of fuse wire consumed in firing. Severity factor was used to integrate the effects of reaction times and temperature into a single variable during torrefaction.

Through years a 'combined severity factor' is introduced for isothermal reactions [19] as follows.

$$R_0' = 10^{-pH} \cdot t \cdot e^{\frac{T-100}{14.75}} \quad (5)$$

where  $t$  is the reaction time in min and  $T$  is the reaction temperature in degrees Celsius.

Moreover, in torrefaction studies the following severity factor has been used [17].

$$SF = \text{Log} \left[ t \cdot e^{\left( \frac{T_h - T_R}{14.75} \right)} \right] \quad (6)$$

where  $t$  is the reaction time of the torrefaction in min,  $T_h$  the reaction temperature and  $T_R$  the reference temperature, both in degrees Celsius.

A combined severity factor for non-isothermal reaction conditions was introduced [20, 21].

$$R_0^* = 10^{-pH} \cdot \int_0^t e^{\frac{T_\theta - 100}{14.75}} dt \quad (7)$$

where  $T_\theta$  is the reaction temperature in degrees Celsius. Since in this work variables used are time and temperature,  $pH$  was removed from the equation. The simplified severity factor used herein for non-isothermal reaction conditions is shown below.

$$R_0 = \int_0^t e^{\frac{T_\theta - 100}{14.75}} dt \quad (8)$$

The Severity factor values according to eq. (8) for each experiment are estimated in Table 1.

Table 1: Severity factor values for each experiment.

t(min)	Ro	logRo
20	2,12E+07	7,33
22,5	2,76E+07	7,44
25	5,13E+07	7,71
27,5	7,51E+07	7,88
30	1,04E+08	8,02
32,5	1,21E+08	8,08
35	1,45E+08	8,16
37,5	1,57E+08	8,20
40	1,73E+08	8,24
42,5	1,79E+08	8,25
45	1,88E+08	8,27
47,5	1,92E+08	8,28
50	2,01E+08	8,30

Table 2: The table shows the mass decrease during the torrefaction process.

$R_0$	$\text{Log}R_0$	$t(\text{min})$	yield%
2,12E+07	7,33	20	75,87
2,76E+07	7,44	22,5	69,04
5,13E+07	7,71	25	62,36
7,51E+07	7,88	27,5	56,06
1,04E+08	8,02	30	49,49
1,21E+08	8,08	32,5	45,89
1,45E+08	8,16	35	41,75
1,57E+08	8,20	37,5	41,15
1,73E+08	8,24	40	40,20
1,79E+08	8,25	42,5	39,90
1,88E+08	8,27	45	39,80
1,92E+08	8,28	47,5	39,70
2,01E+08	8,30	50	39,41

In Table 2, is shown, for each experiment carried out, how mass at starting time ( $m_0$ ) lowers to mass at the end of each experiment ( $m_t$ ). Yield% shows the shrinkage percentage of the mass through time.

Figure 2, as it can be seen below, displays how yields' percentage decreases rapidly for small severity factor values and as severity factor increases this decrease shortens and it becomes more stable. The equation that shows how yield is affected by severity factor is the following.

$$\text{yield}\% = -4 \cdot 10^{-7} R_0 + 82.59 \quad (9)$$

The coefficient of variation was  $R^2 = 0.994$ .

In Figure 3 the percentage of loss of mass during the torrefaction procedure compared to logarithm of severity factor is presented. As it can be seen as time rises yield is less affected. The kinetic equation that shows mass decreasing as logarithm of severity factor increases is given below

$$\text{yield}\% = -37.97 \log R_0 + 353.5 \quad (10)$$

The coefficient of variation was  $R^2 = 0.991$

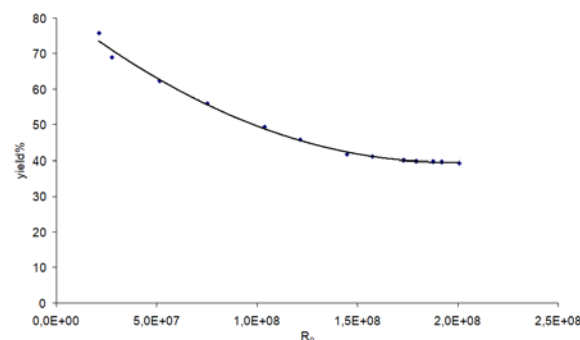


Fig.2: Torrefied cotton mass yield as affected by severity factor

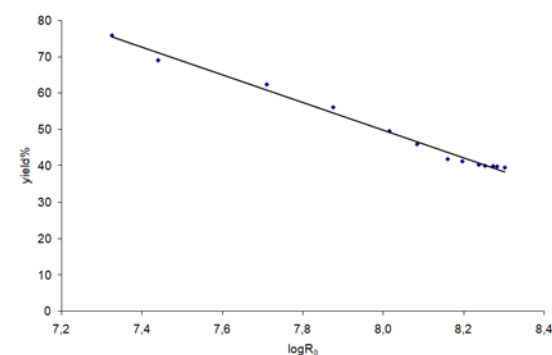


Fig.3: Torrefied cotton mass yield as affected by severity factor in logarithmic form.

Table 3: Gross Heat of Combustion changes through time.

$R_0$	$\log R_0$	$H_g$ (MJ/kg)	$\Delta H_g$ %
2,12E+07	7,33	17,2	5,3%
2,76E+07	7,44	17,6	7,8%
5,13E+07	7,71	17,7	8,4%
7,51E+07	7,88	18,6	13,9%
1,04E+08	8,02	20,1	23,1%
1,21E+08	8,08	20,6	26,1%
1,45E+08	8,16	20	22,4%
1,57E+08	8,20	19,8	21,2%
1,73E+08	8,24	19,9	21,8%
1,79E+08	8,25	19,8	21,2%
1,88E+08	8,27	19,6	20,0%
1,92E+08	8,28	19,4	18,8%
2,01E+08	8,30	19,5	19,4%

Table 3, shows, how gross heat of combustion ( $H_g$ ) increases for different torrefying reaction time. The ideal time that gives the biggest output ( $\Delta H_g$  %) is 30 minutes were  $H_g$  increased 26.1%. The gross heat of combustion for the untreated medical cotton was measured 3 times. Its average found 16.3 MJ/kg and its standard deviation 0.3 (1.9%).

Figure 4 shows the dependence of gross heat of combustion from the severity factor. As it seems a moderate torrefaction optimizes the procedure since maximum  $H_g$  is found at 32.5 minutes reaction time. This dependence is given from the following equation.

$$H_g = -6 \cdot 10^{-8} R_0 + 15.84 \quad (11)$$

The coefficient of correlation was  $R^2 = 0.9$ .

Figure 5 shows how gross heat of combustion grows as logarithm of severity factor increases. The kinetic equation that describes this figure is shown below.

$$H_g = 21.22(\log R_0)^3 + 496.7(\log R_0)^2 - 3868 \log R_0 + 10042 \quad (12)$$

The coefficient of correlation was  $R^2 = 0.918$ .

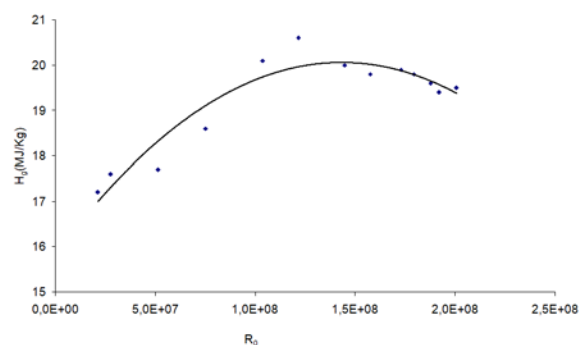


Fig.4: Gross heat of combustion vs severity factor.

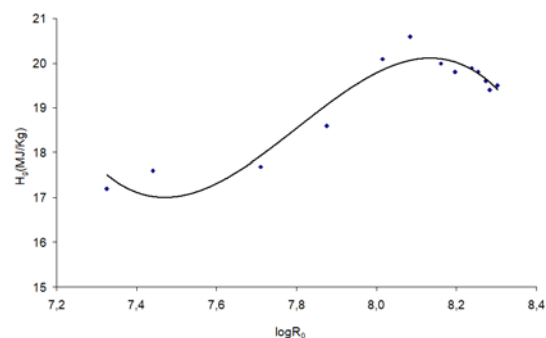


Fig. 5: Gross heat of combustion compared to logarithm of severity factor

## 4 Conclusion

In this study, torrefaction conditions were investigated for increasing medical cottons' gross heat of combustion. Modest treatment conditions were found to maximize its value. Torrefied medical cotton became sterilized at the applied conditions with 26% higher gross heat of combustion compared to untreated medical cotton. As a result of the torrefaction process, cotton is considered a recycled material with enhanced heating value suitable for energy purposes.

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## **Acknowledgements**

Financial support provided by the Research Centre of the University of Piraeus is kindly acknowledged.