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THE IMPACT OF VESSEL WALL THICKNESS ON BURNING RATE OF ETHANOL

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Abstract

A significant influence to burning rate of flammable liquids has vessel wall thickness. Dependence of the burning rate of vessel wall thickness resulting from the thermal balance of a system :flammable liquid and vessel. If the thickness of the walls comes to changes, the heat transfer through the walls of the vessel is changing. The article deals with the velocity of the burning rate of burning time and vessel wall thickness containing ethanol.

Key words

flammable liquid, ethanol, burning rate, vessel wall thickness

Introduction

Burning rate as one of the most important parameters of burning of flammable liquids is using in mathematical dependencies to simulate fire of flammable liquids. Uniform methods to set burning rate of flammable liquids don´t exist in presence. To determine burning rate are using old study results or experimental results achieved by different methods. Burning rate of flammable liquids was getting by different ways and methods in last studies (table 1).

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BURNING METHODS FROM DIFFERENT AUTHORS Table 1

Vessel dimensions	Study citation	Specification
Vessel to cone calorimeter, cylindrical vessel 0,44 m and 1 m	[1]	Burning rate in the vessel without specifications and burning rate on the cone calorimeter
Diameter 8 mm, 10 mm, 12 mm	[2]	Injection into a burning sphere
Cylindrical vessel, diameter 10 mm - 304 mm	[3]	Vessel specifications, material : steal, copper, glass, dimensions and wall thickness

Mass burning rate is defined as burned liquid mass (g,kg) in time unit (min, h) from surface unit (cm2,m2) (8). The parametres of vessel have significant impact to burning rate. The parametres that affect burning rate from characteristics of vessel are shown in Picture 1.

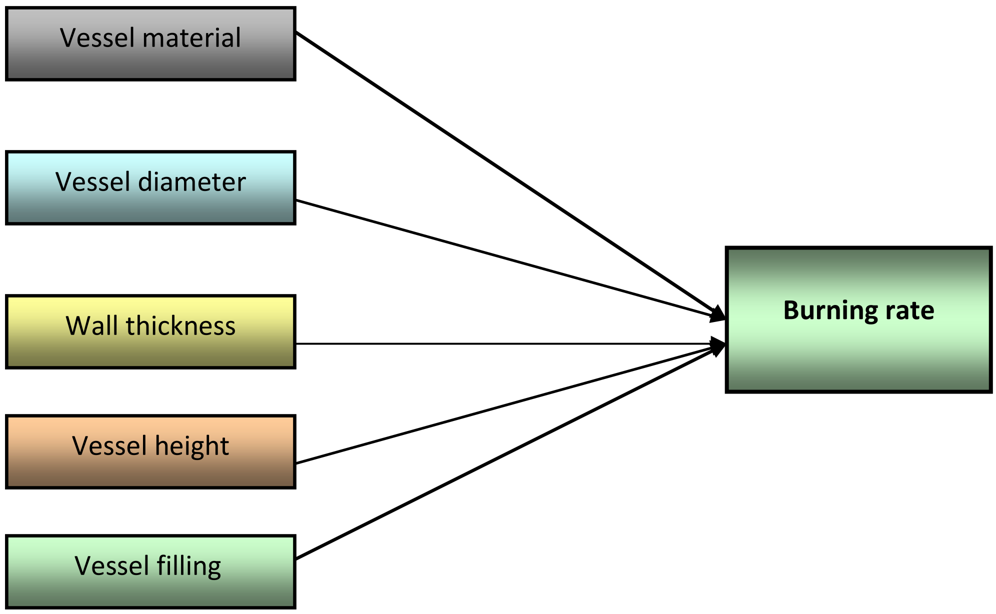

Fig. 1 *Vessel impact to burning rate*

Thermal balance

Heat transfer to liquid at burning of flammable liquids can be divided to heat transfer from vessel walls through flame radiation and through burning residues convention. Heat is transferred from the liquid through the vessel to the ambient. Heat balance between the total heat input and the total heat loss in the combustion system which includes both the liquid fuel and the vessel must be examined (3).

The total heat input into the combustion system $Q_{in,\,s}$ is generally expressed as (3):

$$Q_{in,s} = Q_{cond,l} + Q_{conv,l} + Q_{rad,l} + Q_{cond,v} + Q_{conv,v} + Q_{rad,v} \ , \tag{1}$$

where Q_{cond}, Q_{conv} and Q_{rad} are the conductive, convective, and radiative heats and the subscripts L and v correspond to the liquid fuel and the vessel, respectively.

The total heat loss, that is, the sum of the heat transfer from and heat accumulation in the combustion system $Q_{out,s}$ can be given by correlation(3):

$$Q_{out,s} = Q_g + Q_{rr,l} + Q_{rr,v} + Q_{sens,l} + Q_{sens,v} + Q_{refl,l} + Q_{refl,s} + Q_{v,air} + Q_{v,\sup t} \ , \tag{2}$$

where:

Q_g is the total gasification heat of the liquid,

Q_{rr} is the reradiation,

Q_{sens} is the heat required to increase the sensible heat of a substance,

Q_{refl} is the reflection of the incident radiation,

$Q_{v,\,air}$ is the convective heat from the vessel to the surrounding air and is supstituted by $Q_{v,\,water}$ when the vessel is cooled with water,

$Q_{v,\,supt}$ is the heat loss from the support of the vessel and the pipeline for measuring sensors which penetrates through the vessel.

The model of heat transfer is in Picture 2.

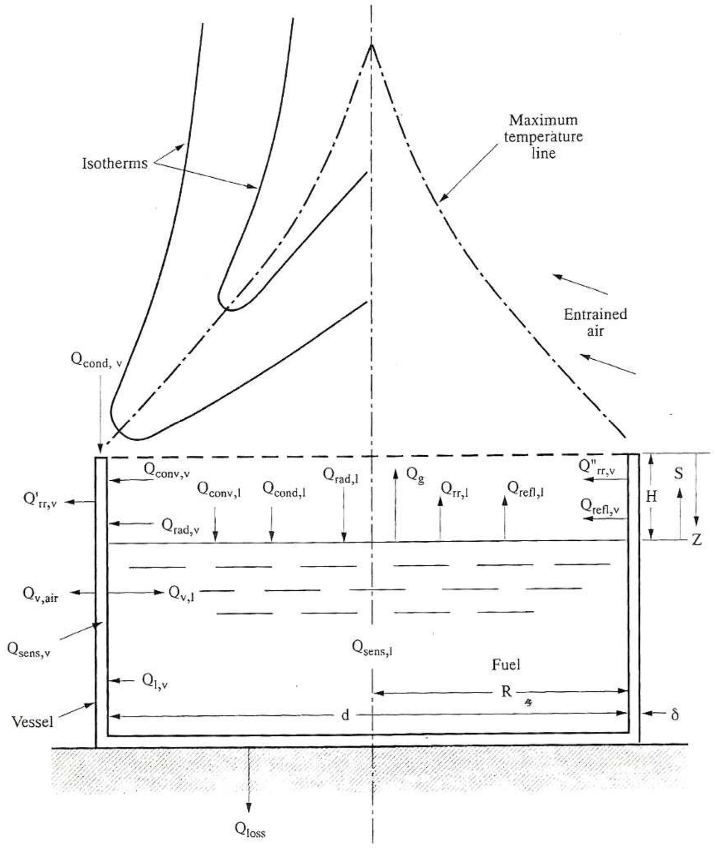

***Fig. 2** Heat transfer in the vessel and liquid [3]*

Heat balance in vessel

Heat input into the fuel

The heat input into the fuel is generally expressed as:

$$Q_{in,v} = Q_{rad,v} + Q_{conv,v} + Q_{cond,v} + Q_{l,v} \tag{3}$$

The radiative heat from the flame to the inside surface of the vessel $Q_{rad,\,v}$, is generally neglected because of its quite low values of surface which are exposed to radiation in comparison with surface of liquid. Radiative heat transfer is not neglected in large liquid decline in relatively large average of vessel over 10 cm. At large ullage heights (H› 0,2d), the convective heat $Q_{conv,\,v}$ becomes large, because the hot gas mixture o fair and combustion products entrained into the ullage of the vessel circulates in the ullage (4) and transfers heat convectively to the wall surface.

Assuming that the radiative heat is transmitted from the isothermal and homogenous flame through a nonabsorbing medium and its reflectivities at wall and fuel surfaces are both equal to zero, the ratio of radiative heats $r = \frac{Q_{rad,v}}{Q_{rad,l}}$ is expressed approximately as (3) :

$$r = \frac{(\phi\sqrt{\phi^2+4} - \phi^2)}{(2+\phi^2 - \phi\sqrt{\phi^2+4})} \quad , \tag{4}$$

where

$$\phi = \frac{H}{R} \quad . \tag{5}$$

From eqn (4) , its seen that r increases with increasing fí and is equal approximately to 1 at H=0.35d. Therefore, the sum of convective heat $Q_{conv,v}$ and radiative heat $Q_{rad,v}$ is expected to be comparable to or larger than that to the fuel surface at large ullage heights. The conductive heat from the flame to the edge of the vessel $Q_{cond,\,v}$ is dominant in small scale pool fires (D≤2cm).

Heat loss in the vessel

The heat loss in the vessel $Q_{out,v}$ is expressed by(3):

$$Q_{out,v} = Q_{rr,v} + Q_{refl,v} + Q_{v,air} + Q_{v,l} + Q_{v,\sup t} + Q_{sens,v} \ , \tag{6}$$

where $Q_{rr,\,v}$ is the sum of reradiations $Q'_{rr,\,v}$ at the outside and $Q''_{rr,\,v}$ at the inside of the vessel wall. The reradiation $Q_{rr,\,v}$ is not negligible when the boiling point of the fuel is high, the ullage height is large, and(or) the thermal conductivity of the vessel is poor, because the temperature of the wall rises to a high level. $Q_{refl,v}$ will also not be negligible at the low fuel level especially when the vessel wall surface is coarse. $Q_{sens,v}$ is negligible compared with $Q_{sens,l}$, because the bulk volume and the specific heat of the vessel material are generally very small compared with those of the liquid fuel.

The convective heat from the vessel wall to the air $Q_{v,\ air}$ is very small compared with that to the fuel $Q_{v,l}$ but becomes dominant at large ullage heights and in the vessel of very poor thermal conductivity and very thin walls. (23)When the height of the vessel is small, the convective heat at the bottom of the vessel $Q_{v,l}$ or $Q_{l,v}$ or $Q_{v,air}$ or $Q_{v,water}$ may become considerable, depending on the fuel, the ullage height, the material, thickness and height of the vessel, and the burning time.

Experimental part

General purpose of the experiment was to monitoring graphic dependency of burning rate in time in conatiners with different wall thicknesses.

The dimensions of the vessel are shown in Table 2, as well as vessels material.

THE DIMENSIONS OF THE VESSELS Table 2

Vessel	Inner diameter of vessel [mm]	Wall thicknesses [mm]	Vessels material	Height [mm]
thick	60	8	Structural steel	45
Moderate thick	60	4	Structural steel	45
thin	60	2	Structural steel	45

Experiment was made in two steps, we followed burning rate parameter by change of wall thicknesses:

1. Filled with ethanol at 50 % (H □ 0,2 d) (Picture 3.)
2. Filled with ethanol at 100 %) H = 0) (Picture 4).

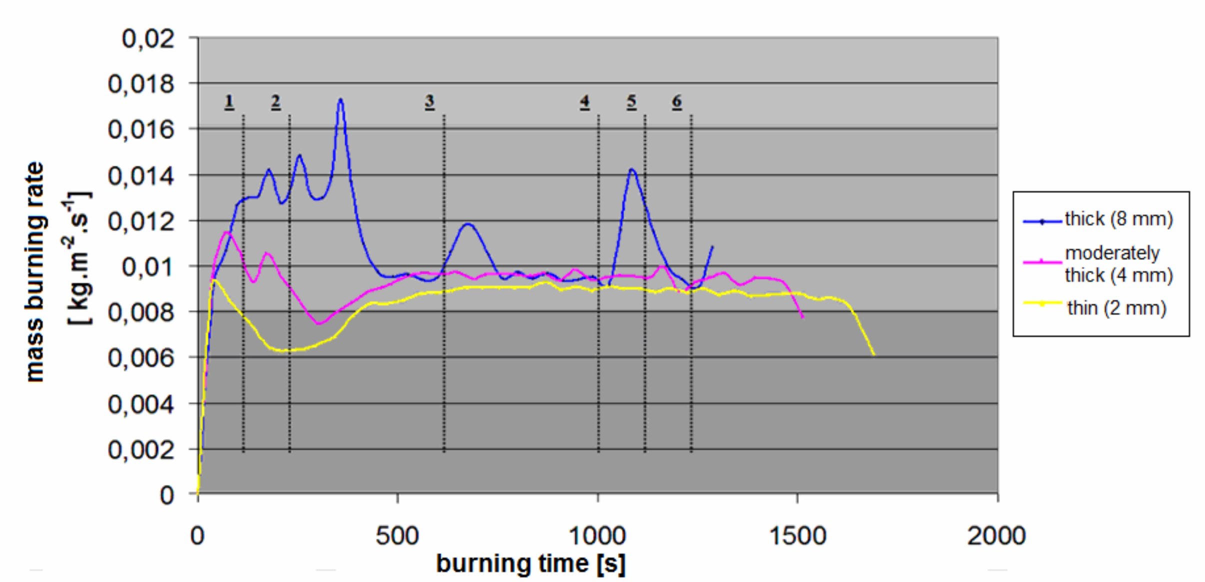

Fig. 3 *Ethanol mass burning rate in dependency of burning time*

Maximum of mass burning rate was for vessel, which had thicker walls (8 mm) and the longest time of burning was for thin – walled (2 mm). By comparing the result time of ethanol burning in vessels with different wall thickness was found, that the burning time in thin – walled vessel, compared with thick – walled is extended by about 750 seconds, wchich corresponds ≅ 22 %.

The curves in Picture 3. Can be divided into 3 parts. In the heat balance of the curve in Picture 3. Describes the following process:

1. Transfer of energy from the flame to vessel walls and flammable liquid, when the vessel with thick wall reaches higher mass burning rate, than vessels with thin walls.
2. Stabilization of the mass burning rate as a result of vessel walls and liqiud partially overheating.
3. Subsequent changes in the final part of curve in consequence lack of oxygen and low levels of flammable liquids.

Vessel with wall thickness of 8 mm is more complicated course of the curve, while the remaining two curves have almost the same course of clearance of temperatures. It is caused by thick walls, which absorb a larger share of heat from the flame. This reduces the proportion of energy defection from the vessel walls into the environment ($Q_{rr,v}$, $Q_{v,air}$).

Thick – walled vessel creates good insulating conditions for the energy produced by burning. The thin – walled vessel, heat penetrates more easily into the surrounding of the vessel and $Q_{rr,v}$ $Q_{v,air}$ share powering in the relationship (6) is increasing.

Increased of mass burning rate also means increase the amount of flame, which is described by mathematical relationships in studies (5,6,7). During the burning was captured flame in photograps shown in Picture 4. Images were made in the positions shown in Picture 3.

Position	**Thick (8 mm)**	**Moderate thick (4 mm)**	**Thin (2 mm)**
1			
2			

Position	Thick (8 mm)	Moderate thick (4 mm)	Thin (2 mm)
3			
4			
5			
6			

Fig. 4 *Height of the flame during burning*

Dependence of burning rate to flame hight was confirmed in the second part of burning process description.

Differences at the beginning of burning rate curve are caused by transfer system vessel-liquid. It results of images comparation and burning rate curve with thick wall (first part of Picture 3).In this part of curve, the burning rate reaches significantly higher values as in the other cases, however this fact is not noticeable in images, it is in line with heat transfer through the vessel wall. In first part, the highest values achieves the vessel, which has thick walls while the flame is the same as in case of thin and moderately thick vessel, because the wall of the vessel consumes bulk volume of energy to its heating.

In the second part of the experiment (Picture 5) ethanol reaches edge of the vessel (100 % filling) (experiment made in the same conditions).Maximal burning rate is similar to previous experiment. Ethanol was burning longest in the vessel with thin walls and it was burning shortest in the vessel with thick walls. The burning in thin-walled vessel was prolonged approximately about 750 seconds (10 %).

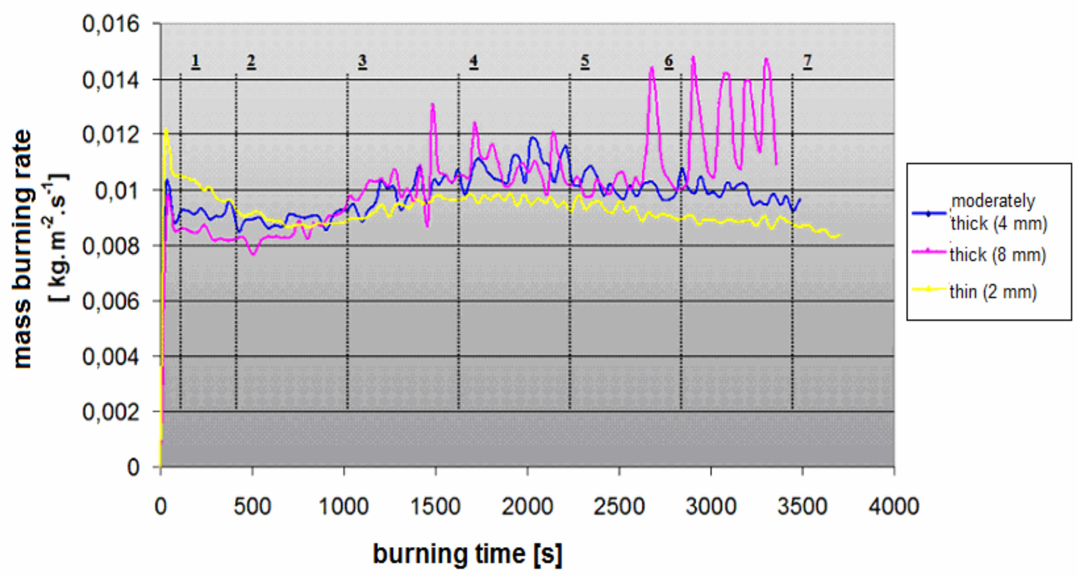

Fig. 5 *Ethanol mass burning rate in dependence on burning time*

In curves comparison in Picture 4 we can see that the largest growth of mass burning rate in begining part achieved curve of thin-walled vessel. It differs of Picture 3 in experiment 1. This fact is caused by burning near vessel aperture. Consequence of this is both of ideal access of flame to oxygen and vessel wall overheating is progressive. Especially overheating of thin-walled vessel occurs faster and also therefore the growth of the curve is faster in first part of graph. Subsequently the burning rate jiggles (in case of every vessel). This is caused by desrease of the liquid level and consecutive deficiency of the oxygen.

The behavior of the flame during the burning of the liquid is in the Picture 6.

Position	**Thick (8 mm)**	**Moderate thick(4 mm)**	**Thin (2 mm)**
1			

Position	Thick (8 mm)	Moderate thick(4 mm)	Thin (2 mm)
2			
3			
4			
5			
6			

Position	Thick (8 mm)	Moderate thick(4 mm)	Thin (2 mm)
7			

Fig. 6 *Height of the flame during burning*

Both of the height of the flame and the burning rate reach more stable values at the 100 % vessel filling as at the 50 % vessel ethanol filling.

Temperature distribution in liquid

Changes of burning rate are in the line with change of thickness of vessel walls and with the temperature distribution in liquid. For better understanding of the problem, temperature measurement was realized in the vessel by thermocouples. The thermocouples were distributed in 1/3 of vessel height. The first thermocouples was placed close to the wall of the vessel, and second one in the middle of the vessel. Above the thermocouples was 25 g of liquid, which correspond with thermocouples distribution in the middle of liquid, because the liquid level was in 2/3 height of the vessel.

The result of the experiment is seen in picture 7. The vessel with thin wall had faster increase of temperature at the beginning of burning, in contrast to thick wall, which absorb energy, and increase of temperature seems to be linear. After a while, the vessel with thick wall gets higher values, which is caused by releasing of accumulated energy in the walls of the vessel.

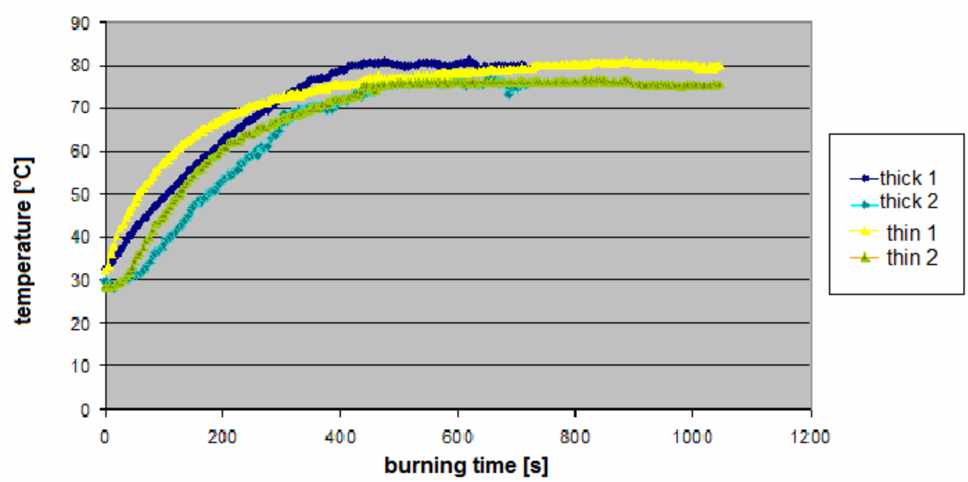

Fig. 7 *Temperature process on the wall (curve 1) and in the middle (curve 2) of the vessel in dependence on burning time*

Discussion

Influence of thickness of vessel walls has significant influence to burning rate. The increase of burning time increased about 22 %. Closer differences were achieved in experiment no. 2, because of better access of ethanol toward air, and so the part of transfer energy is decreasing. Differences between thin and thick walls of the vessel are caused by heat transfer from vessel to surround.

Connection between flame height and burning rate was published by many authors. Experiments described in this study show flame behavior during burning and they are compared with burning rate. The curve of burning rate was divided to 3 parts. In the first part, the biggest differences were caught; however, the height of flame doesn't change.

While in the second and third part of the figure, the dependence is manifested. It is caused by heat transfer and by energy balance in the vessel. In the first part, the energy is released to liquid and to walls of the vessel. In the second and third part, the energy is utilized for liquid gasification, and participates in height of flame.

Conclusion

According to frequent utilization of burning rate, a parameter of flammable liquid burning is not much measured. Nowadays, the burning rate comes to the background. Differences and variances from mathematical simulations are often solved with correlation of different coefficients. In spite of their usage, significant inaccuracies are brought into real behaviour of liquids. Therefore, significant role plays experimental data verification, which are utilized in mathematical modelling. This fact is in it more remarkable, that experimental results, which we measured, confirm, that change of wall thickness increases burning time about 10.22 %, whereby literature and mathematical formulas don't allow this parameter.

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