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THE STUDY OF A CHARCOAL STOVE

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ABSTRACT

This paper investigates Charcoal stoves. Many types are looked at and examined in search for systematic design method leading to a more accurate method for producing and forming the templates. It is predicted that, with growing charcoal production and use, the use of charcoal stove in the average low income home may grow. Besides as long as trees' planting is made law and obeyed, charcoal as a source of energy will perhaps be one of the most reliable and renewable energy source (other than solar energy) in Nature, on which a nation can rely for part of energy requirements if necessary balance of reforestation and deforestation is maintained.

INTRODUCTION

Fig.1 shows a simple charcoal stove with the dimensions as shown.

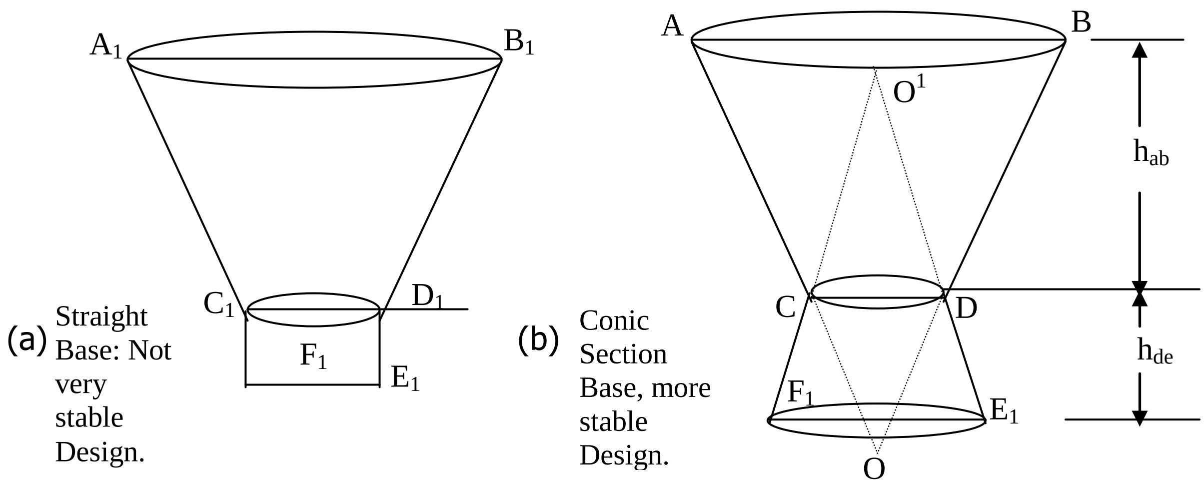


Fig.1. Simple Design (Constructions of Charcoal Stoves. The stove is easily formed from a sheet metal which can easily be formed to a cone but truncated to a frustrum so as to form the stove. Two types of designs are considered Fig.1(a) with base C,D,E,F_1 seems to be unstable, and so no further work will be done on it. Fig.1(b) has both parts of the stove designed and constructed from conic sections. Depending on the design, AB≥CD and in some designs and constructions, and in a few design AB<CD. However, and in general, designs and constructions with AB>CD are more common. With the same argument, and depending on the quantity of charcoal the user had in mind, $h_{ab} > h_{de}$; in which case the volume of the top part of the stove > the volume of the bottom. There are designs for commercial, family and small types – students cooking types. All these can be taken into account in this simple study.

THE BASIC DESIGN CONCEPT

A cone is the section of a circle which when it subtends and angle θ at the centre, it can be folded to form a cone. That is figure AOBCA can be folded to form a cone such that the arc ACB is;

Arc = $^{2\pi\theta}/_{180}$ ----------- (1)

where;

r = radius of the circle

θ = angle AOB in degrees

The side of the cone is r_ϕ

whilst the base of the cone has a radius of

$r_\phi = {}^{r_\phi \theta}/_{360}$ -----------------(2)

where r_ϕ = radius of the base of the cone.

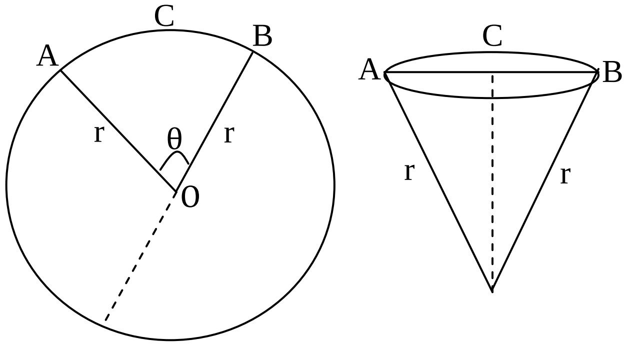


Fig.2:

Volume of a Frustrum

The frustrum is a truncated cone, fig.3. Its volume for a given design is easily calculated when the whole cone from which it is made is taken into account, fig.4.

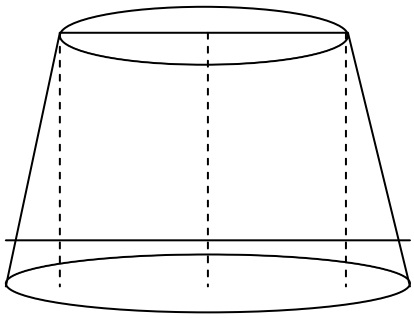


Fig.3: Structure of a Frustrum

The volume of the cone OAB is

$$V_{oab} = \frac{1}{3} h_1 \left(\frac{AB}{2}\right)^2 \pi \text{ ---------------2}$$

and

$$V_{oa_1b_1} = \frac{1}{3} h_2 (OC)^2 \text{ ---------------3}$$

So that the volume of the Frustrum AA_1B_1B is

$$V_1 = \frac{\pi}{3}\left[h_1 AC_1^2 - h_{c_2 o} AC_2^2\right] \text{ --------4}$$

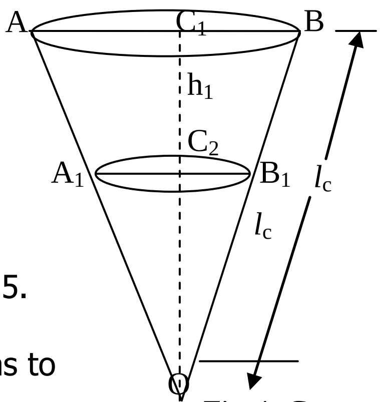
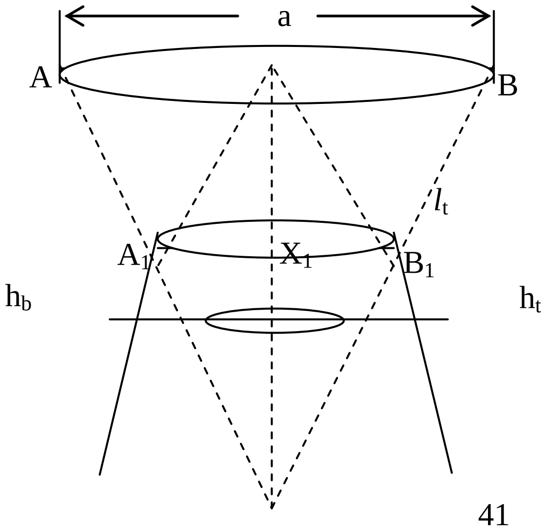


Fig.4: Cone

Design/Construction Options of Stoves

The standard designs/construction options are two truncated cones and the frustra from them are joined or welded together at the smaller parts of the frustra, figure 5. That the two cones, AOBX, and $A_2O^1B_2X$ are joined together at $A_1X_1B_1$ where their frustra are joined welded together so as to form the stove. The diameters at the joining



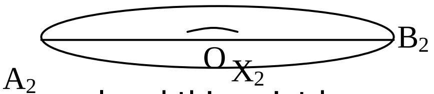
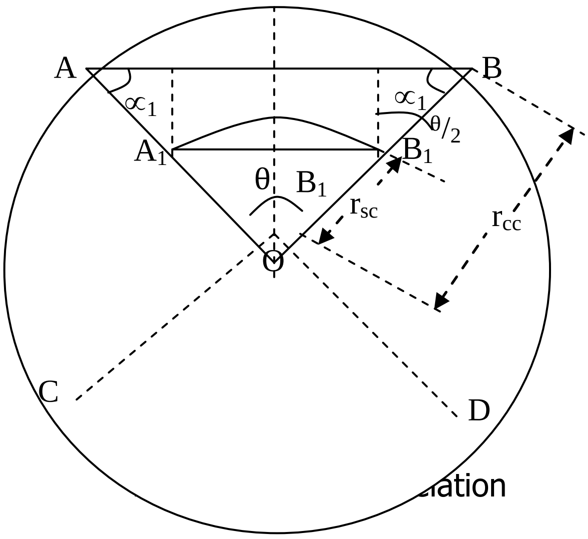


Fig.5: Stove Sketch

lines have to be equal and this point becomes important in the choice of two cones to be used. Both need not be equal because the lower frustra is usually smaller than the top which normally holds the charcoal whilst the low part holds the ash resulting from the burning action. The waste parts of the cones, $A_1OB_1XA_1$ and $A_1O_1B_1X_1A_1$ may be discarded, but could be used for making smaller stoves. Therefore in routine designs and if commercial plans are in mind, sheets should be chosen so as to optimize the materials to be used for the designing and making charcoal stoves.

Use of Conic Properties

Consider using the properties of a cone, figure 6, radius r_c being also the radius of the circle ABCA, a cone of angle θ can be made from the circle sector AOB; similarly a frustrum far making the top of a stove can also be constructed. The base circumference of the top part of frustrum (cone and the arc of the cone are equal. That is,



OBθ = OAθ = ABп -------------------5

and

OB = ABп/θ

Let us consider the case of a circle such that BB_1 = 14cm and the height of the frustrum BY is 10.12 and BY = 8.76cms

Then $cos\frac{\theta}{2}$ = 10.70/13.8

and $^{\theta}/_{2}$ = -----------------------or θ =

let us consider the circle of radius 70cms. Then if we fix B_1B = 14cm. OAθ = 70θ = ArcACB = 2пr_c, the top circumference of frustrum.

From fig.2, and its sector OACB,

$cos\frac{\theta}{2} = \frac{B_1Y}{BB_1} = \frac{10.92}{14} = 0.78;\ \frac{\theta}{2} = 38.74^0$

and $sin\frac{\theta}{2} = \frac{8.76}{14} = 0.6257$ or $\frac{\theta}{2} = 38.735^0$

hence θ = 77.48^0 = 77.5^0

The arc ACB = 70× 77.5 × $^{п}/_{180}$ = 94.68cm

and the radius of frustrum is

2пr_c = 94.68 or $r_c = \frac{94.68}{2\pi}$

= 15.07cms

The radius of the lower diameter is 70 – 14 = 56cms

The arc is $56\times77.5\times\frac{\pi}{180}$ = 75.75cms

r_{bc} = 75.75/(2п) = 12.06cms

Then the frustrum as designed from the properties of the cone and the related circle is as shown in figure 7.

The ratio of the top diameter to the bottom is $K = \frac{AB}{A_1B_1} = \frac{r_{ct}}{r_{cb}} = \frac{15.07}{12.06}$; K = 1.25

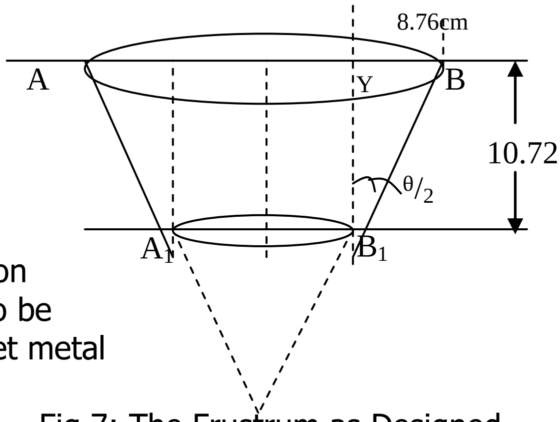


Fig.7: The Frustrum as Designed

The Template Preparation

Charcoal stoves (1) are constructed by blacksmiths/sheet metal artisans who use templates cut from metal sheets or carbon and for tracing out the outline of the stove to be constructed. The cut out sheet from the sheet metal is then folded neatly to the shape required.

To obtain the template for forming the frustrum, we draw a line OA and measure the angle 77.5^0 and draw the line OB. With radii 70cms and 60cms draw the arcs AB and A_1B_1 cutting the lines OA at A and A_1, and OB at B and B_1. In this way the arcs AB and A_1B_1 are constantly separated by the distance 14cms. By joining AA_1 to BB_1, and with proper construction steps, the frustrum may be made. Note that AB B_1 A_1 A is the template, and if formed can be used repeatedly for making as many frustrums from it. In another design, the frustrum diameters are 30cms & 22cms, and the slope side or distance between the top and bottom diameters is 13cms. In this case the slope side of the cone is as long, as about 150cms. In such a case it is not always easy to find an instrument of this radius to draw out the necessary arcs of circumferences 30π and 22πcms respectively. In this case the template is formed and repeatedly used.

A SECOND APPROACH

In this approach, two radii 16cms and 6.3cms (and their ratio 2.54) are drawn so that the distance between them is 16.0 – 6.3 = 9.7cms, as the slope of the frustrum, fig. 3.

If the templates are cut along $ACBB_1C_1A_1A$ two frustrums of radii 8cms and 3.15cms are easily made and the slope side is 9.7cms. This result is very easily demonstrated by cutting out the templates on paper and fold them to form of the two frustrums of height 9.7cms, but the top and bottom diameters remain 16cms and 6.3cms respectively, the angle of cut, θ is 180^0.

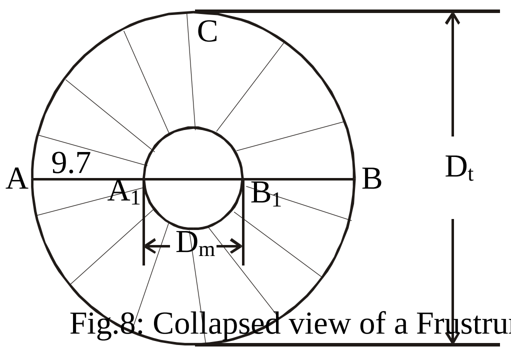


Fig.8: Collapsed view of a Frustrum

If the frustrum is to be constructed the slope side should always be the distance between the top and the lower diameters. These dimensions have to be determined as may be necessary or specified for a given frustrum. A general template depending on the dimensions of the frustrum is as shown in figure 4. One approach is to see the frustrum with the bottom small circle $A_1C_2B_1A_1$ held in a pulled up position with the radius r_D and the slope side l and radius r_t to form the frustrum, but the cone with r_D forming its base diameter removed.

Consider another stove of dimensions
D_{top} = 32cms; D_{middle} = 12.6cms
D_{bottom} = 18cms, l_s = 14.5cms for the top parts

This design is similar to figure 5.

Let us use these dimensions to design the frustrum so that we can construct it. There are radii r_m^1 & r_t^1 such that,

$r_m^1\theta = 12.6\pi$ ---------------------------------------(1)
$r_t^1\theta = 32\pi$ --(2)
$r_b\theta_b = /8\pi$ ---(2a)
Also r_t^1 and r_m^1 are related by

$R_t^1 - r_m^1 = 14.5, \theta$ ---------------------------------(3)
and
$K = r_t^1/r_m^1 = 32\pi/12.6\pi = 2.54$ -------------------(4)

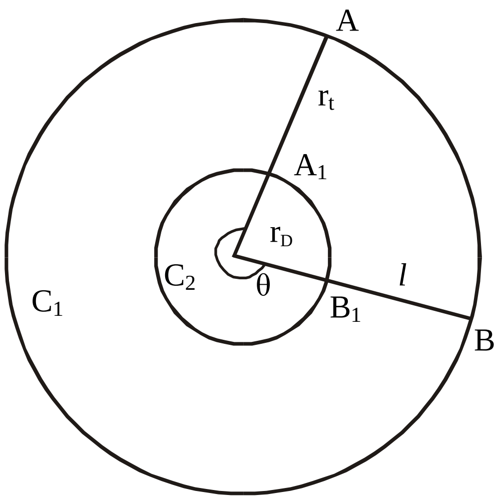


Fig 9: Frustrum Design, D.

Equations (1) to (4) are fundamental practical designs and construction equations of a frustrum.
By solving equations (3) & (4) for r_t^1 & r_m^1 we have
r_t^1 = 23.916 & r_m^1 = 9.416cms, hence $r_t^1 - r_m^1 = 14.5cms$
From equations (1) & (2) we may determine θ as,
(a) $\theta = 12.6\pi/9.416 = 4.204$ rad $= 240.87^0$
(b) and $\theta = 32\pi/23.916 = 4.204 = 240.87^0$
These two results agree as expected.
Using this approach, the template are as shown in figure 10. in which the included angle is 241^0 or the excluded and is $360^0 - 241^0 = 119^0$
The template for constructing the top of the stove is then marked out as shown in figure 10, as

ABC C_1 DEA.B

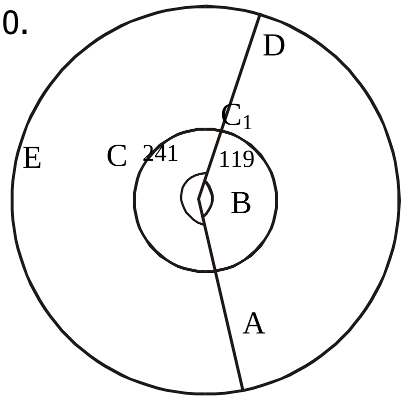


Fig.10: Formation of the template

THE GENERAL DESIGN CONCEPT

It is now possible to state the general equations for the design of any template for a frustrum which in most cases is a truncated cone. The diameters AB = D_t and A_1B_1 = D_m (or radii r_t and r_m) as well as the slope side l_s must first be fixed or decided on by the designer. The distance between the top and middle diameters is the slope side of the frustrum, so that (fig.11)
$D_t - D_m = 2l_s$ -----------------------------------(5)

In cone design, the base diameter is the largest base and progressively becomes zero at the tip and when the cone is seen from the top to the base it will be like figure 12 with lines radiating to the base from the tip top of the cone.

However, there is a diameter, D_t^1 of the cone which suspends angle θ at its centre so that the product of this diameter and the angle θ<360 gives the desired diameter of the frustrum. If these two diameters and hence the corresponding radii are; D_t^1, D_m^1, r_t^1 and r_m^1, the design equations becomes

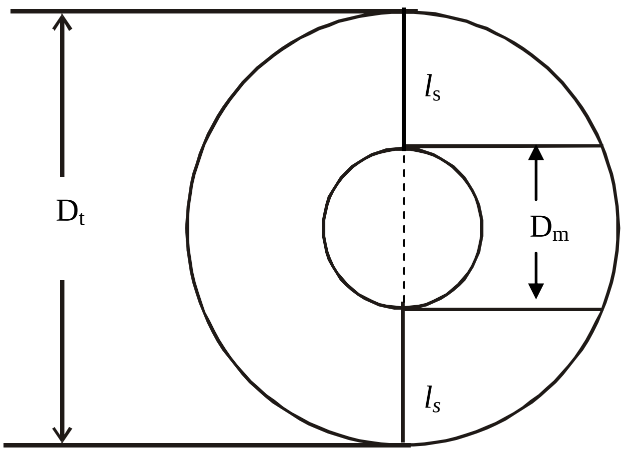


Fig.11: Frustrum Diameters Design

$r_t^1\theta = \pi D_t$ ------------------------------(6)

$r_m^1\theta = \pi D_m$ ----------------------------(7)

$r_t^1 - r_m^1 = l_s$ ---------------------------(8)

and

$K_f = r_t^1/r_m^1 = D_t/D_m$ -------------------(9)

Solving for r_t^1 and r_m^1, we have

$r_t^1 = l_s K_f /(K_f - 1)$ ---------------------(10)

$r_m^1 = l_s /(K_f - 1)$ -----------------------(11)

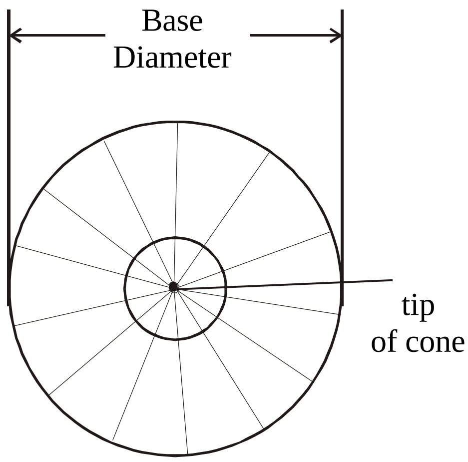


Fig.12: Cone seen from tip to Base

The value of θ may be determined from either equation (6) or (7). That is

$\theta_{rad} = \pi D_t/r_t^1 = \pi(K_f - 1)/(l_s K_f)$ ---------(12)
or expressed in degrees,
$\theta = 180D_t(K_f-1)/(l_s K_f)$...................(13)
This method can also be used to calculate the dimensions of the relevant cone. That is from figure 6 and using similar triangles concept,

$\sin\frac{\theta}{2} = \frac{1}{2}(D_t - D_m)/l_s$ ------------------(14)

So that the length of the relevant cone is

$OB = \pi D_t/\theta$ -------------------------------(15)

and the height of the cone is

$h = \sqrt{OB^2 - r_t^2}$ ----------------------------(16)

THE DESIGN PROCESS FOR A FRUSTRUM

The design process for a frustrum and from the study so far is for the designer to be sure of what size he has in his mind. The generalized frustrum is as shown in figure 13.

From equations (1) to (4) we have,

$$r_t^1\theta = 2\pi a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

$$r_m^1\theta = 2\pi b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

$$r_t^1 / r_m^1 = \frac{a}{b} = K_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots 19$$

$$r_t^1 - r_m^1 = l_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 20$$

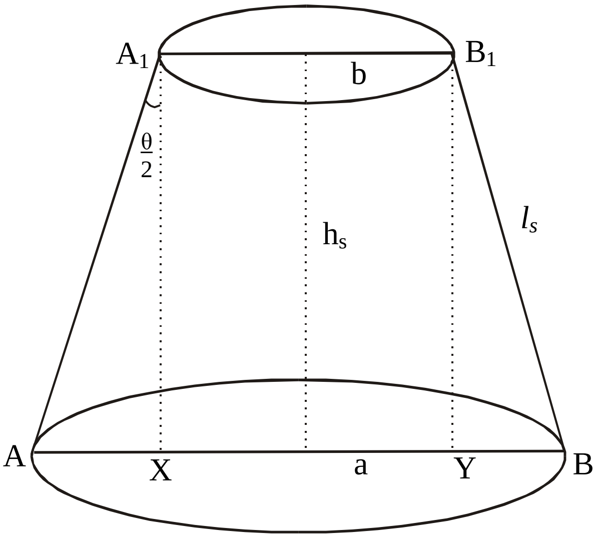


Fig.13: Frustrum Design

In the design process to be followed, a,b & l_s are fixed.

When the frustrum becomes a simple cylinder, a=b; $r_t^1 = r_m^1$ & $h_s = l_s$

The cylindrical type of stove [1] is also possible. It is indeed the simplest.

The design process reduces to the determination of r_t^1, r_m^1 and θ. Indeed the key item in the design is to find θ. When these values are known, the template can be traced on a sheet metal or a cardboard. Many frustrums can be made from the one template. In each case the template is placed on right metal sheet gauge selected for the purpose, and it is cut out to form the frustrum. The ends of the piece cut out are joined. The lower frustrum of the stove is also obtained, and the stove is accordingly constructed by joining the top to the bottom.

CASE STUDY/DESIGN

Construct a picture in the mind of the stove(1) to be designed, and sketch it out as shown in figure 14.

Decide on, l_s and a & b such that $2.5 \le \left(a/b\right) \ge 1.25$ or, $1.1 \le \left(a/c\right) \le 0.5$. If the space where the stove is to be used is important, then this should be taken into account. The sizes of pots on it and hence the quantity of food to be cooked on it are all important in the size decision. For example, a students', one or two persons cooking size stove should be different in size from that of a family type; just as the size of a restaurant cooking size is equally bigger.

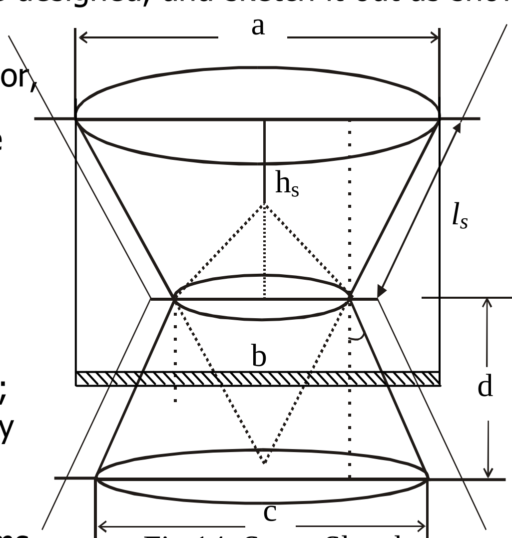


Fig.14: Stove Sketch

Now let a=15; b=11.8, l_f=13.5 and c=18.6, all in cms.

Then $a/b = r_t^1/r_m^1 = 15.6/11.8 = 1.32$ or $r_t^1 = 1.3\ r_m^1$

$$r_t^1 - r_m^1 = 13.5$$

Solving; $r_t^1 = 55.69$, $r_m^1 = 42.19$ (see equations 10 & 11)

$\theta_t^1 = \theta_m^1 = 100.8^0$ (see equations 6 & 7)

Note that;

$r_t^1\theta_t^1 = 2\pi a = 98.02cms$ & $r_m^1\theta_m^1 = 2\pi b = 74.14cms$

With radii, 55.69 & 42.19, the arcs of lengths 98.02cms & 74.14cms are made, but the angle enclosed is 100.8^0, figure 10.

For the lower part of the stove, the design process is more or less repeated. Then c/a=0.8 or c=25cms

so that r_b =12.5cms

Let the slant (slope side =12cms)

The design cone for the base parameters(fig.16) are

$r_b^1 - r_m^1 = 12cms$

$r_b^1 / r_m^1 = 1.32 = {r_b}/{r_m}$ and $r_b = 15.6$ for $r_m = 11.8$

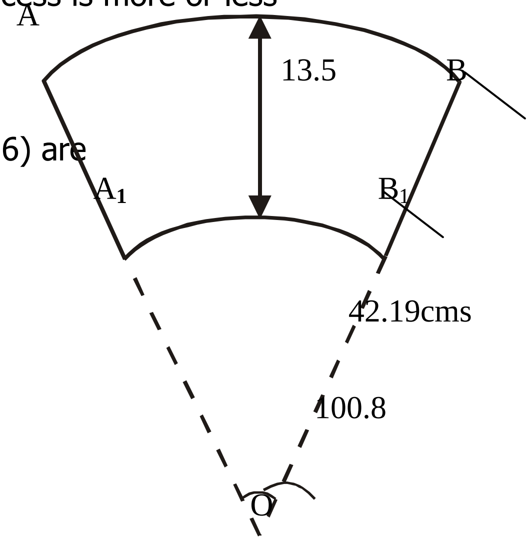


Fig.15: A Template/Sheet Piece for the Frustrum

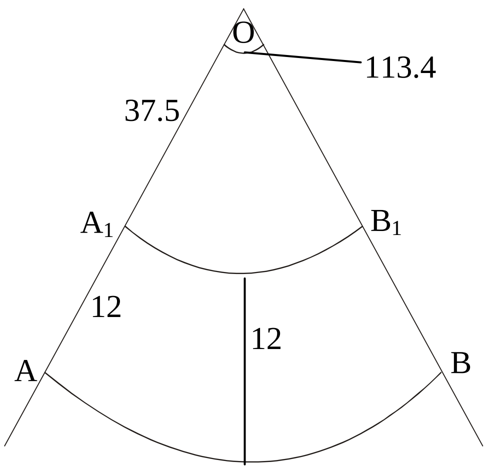
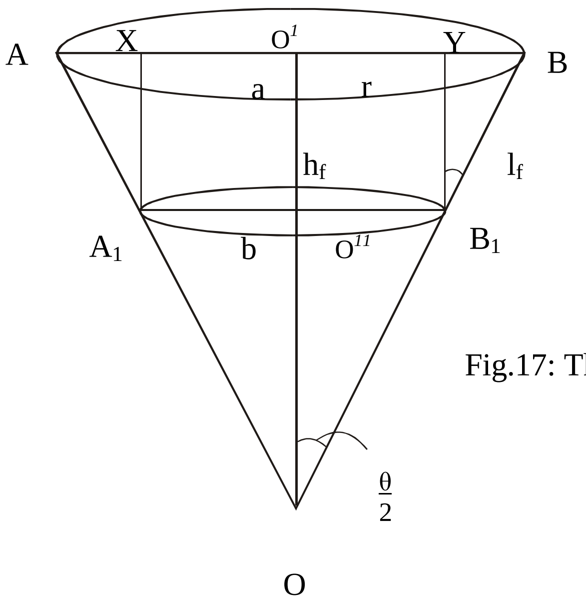


Fig.16: Base Template/Sheet/Piece of Stove



Key

a = AB = 2O^{1}B = 2O^{1}A

b = A_1B_1 = 2O$^{11}B_1$ = 2O$^{11}A_1$

Fig.17: The Cone's Representation

So that solving these equations

$r_m^1 = 37.5; \ r_b^1 = 49.5$

Then,

$37.5\theta_m = 2\times 11.8\pi; \ \theta_m = \frac{23.6\times 180}{37.5} = 113.3$ degrees

$49.5\theta_m = 2\times 15.6\pi; \ \theta_m = \frac{31.2\times 180}{49.5} = 113.45$ degrees

Both are basically equal.

THE CONE INVOLVED IN THE DESIGN

The Cone from Which the Top of the Stove Is Formed

In the design process [3] of the two parts of the stove, means four cones are involved: the two cones for the actual stove and the other two cones for forming the arcs, thus giving the three circumferences; namely, the top, middle and base, fig.14.

The cone from which the frustrum is made is given by (fig.17)

$OB^2 = O^1B^2 + O^1O^{12}$ as a general equation. And for the specificare, we have

$Sin\frac{\theta}{2} = YB/l_f = (15.6 - 11.8)/13.5 = 0.27536$ and $\frac{\theta}{2} = 15.9836^0$

B_1O Sin15.9836 = 11.8 or B_1O=42.85cms

BO = 42.85+13.5 = 56.35cms

$O^{11}O=B_1O$ cos15.9836 = 42.85 cos15.9836 = 41.1934

$h_f = (O^1\theta^{11}) = l_f \cos\frac{\theta}{2} = 13.5\cos 15.9836 = 12.9781$

$O^1O = OO^{11} + O^{11}O^1 = 41.1934 + 12.9781 = 54.1714$

Then, 56.35^2 should be equal to $54.1714^2 + 15.6^2$, but there is a calculation error of 2.58 or 4.5%.

The cone's base, height and slope side are 31.2, 54.17 and 56.35cms respectively.

The Cone Size for Forming the Frustrum of the Stove

The resulting cone dimensions used to form the cone of the frustrum are (figure 16)

$r_t^1 = 27.845cms$ and AB = 55.69cms

$r_m^1 = O^{11}B_1 = 21.095cms$

$r_t^1 - r_m^1 = l_s = 13.5 = BB_1$

By repeating the routine calculations, but using the appropriate numerical values
we can have the following.

$$Sin\frac{\theta}{2} = YB/BB_1 = \frac{1}{2}(AB - A_1B_1)/BB_1 = 6.75/13.5 = 0.5$$

$$\frac{\theta}{2} = 30^0 \, or \;\; \theta = 60^0;$$

$$h = O^1O^{11} = 13.5\cos 30 = 11.69cms;$$

$$B_1O\sin\frac{\theta}{2} = 21.095$$

and

$$B_1O = 42.19cms$$

$$OB = OB_1 + B_1B = 42.19 + 13.5 = 55.69cms$$

$$OO^1 = h + h^1 = 11.69 + OB_1\cos 30 = 48.228$$

And it is easily shown that $OB^2 = O^1O^2 + O^1B^2$ with a computational of only 0.07.
It is seen that AB = OB

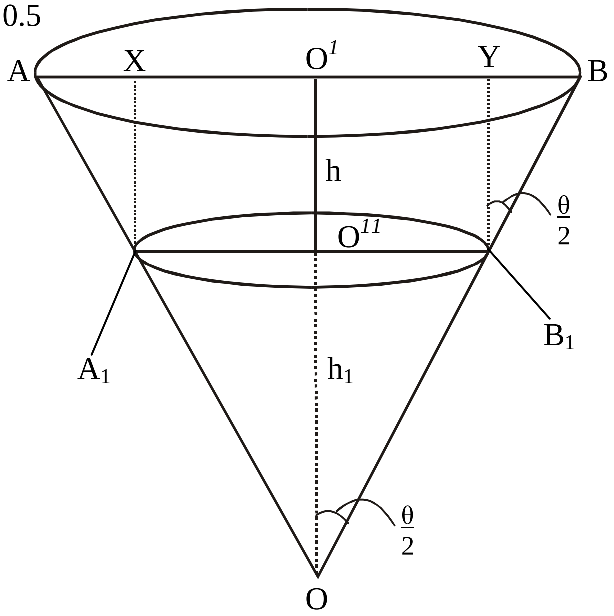


Fig. 18: The Cone: AB=OB

This is a very special cone (fig. 17) whose base diameter is equal to the slope side. Perhaps there is something to learn from it in future.

THE VENT AND CHARCOAL HOLDER

There is need for an air vent at the lower part of the stove and can be used to control air flow. There is also the charcoal holder, usually a metallic sheet perforated with sufficient holes. Its diameter is slightly more than then A_1B_1, figure 17. Experience show that the number and size of holes is responsible for the efficient performance of the stove. Figure 18 shows the sketch of this arrangement for the stove. The number of holes may follow a trial and error approach initially until the design process is completed. As a case study, a stove was purchased and it was only when more holes where added that the stove performed effectively and satisfactorily. Let us add here what internet printout stated: "Nearly two million people, mostly children die each year because of smoke from cooking fire." About 80% wood harvested in Africa is used for cooking. But yet, more efficient smokeless charcoal stoves can reduce the amount of fuel used. A more detailed research may be necessary in the whole area of firewood, stoves and trees planting, and the production of charcoal from firewood so as to find out whether or not the quantity of charcoal from a given quantity of firewood does not have and advantage over using firewood from which the same charcoal was produced.

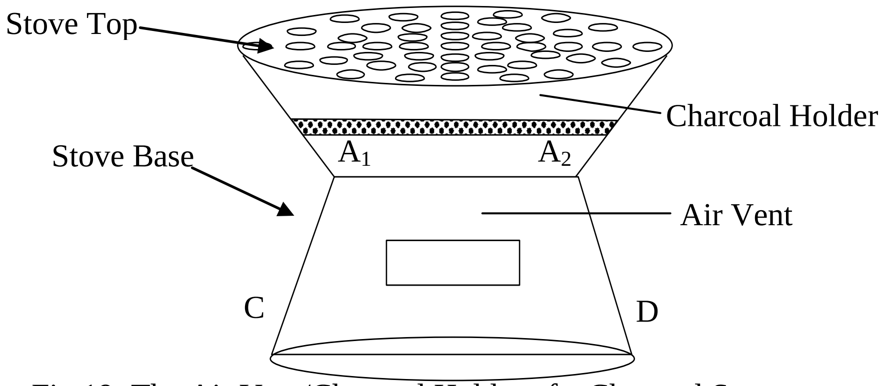


Fig.19: The Air Vent/Charcoal Holder of a Charcoal Stove

CHARCOAL STOVE MAKING TECHNOLOGY

The study of the frustrums with a view to making charcoal stoves [1] is in the low technology spectrum [2]. But it appears there is room for further development of various types of low technologies, for these types do affect basic life system and indeed many small entrepreneurial practices can come from them. Consider for example the expansion of black smiths trade who may work in this area if cooking and drying processes were properly developed using charcoal stoves and charcoal as an energy source. Closely related to this, is commercial forest development which must now be enforced by Law for it appears charcoal production is ever increasing nationwide. Low technology systems [2] employ people with relatively low levels of education or skills but such must be trainable. Their skills are manual based with some semi automatic operations. Research expenditure is very small, particularly since low technologies have become stable because they have been on for a very long time, and are fully developed. Perhaps training people to earn a living from them is what is now most important. The country can greatly benefit if more small scale entrepreneurs [5] grow from it, and such similar ventures and the related job creation. Finally, the products from low technologies are mainly the types that satisfy basic human needs of food, shelter, clothing and many basic human services, such as welding, plumbing, electrical services and today, the ever growing information technology.

CONCLUSION AND COMMENTS

A simple design process has been developed in this paper. The black smith and related sheet metal workers [4] have not fully related their templates to a strict design before construction. With the approach outlined in this paper, improved construction methods will be developed. In this way skills and practices of the sheet metal worker can be improved upon, and better stoves, even those lined with ceramic may reach the market place [2].

REFERENCES

Stephen Karekezi & Timothy Ranja, "Renewable Energy Technologies in Africa" AFREPREN publishers, 1997.

VITA (Volunteer Specialists) "Village Technology Handbook", Rev. Edition, 1930.

Edward V. Krick Edward "An Introduction to Engineering and Engineering Design" John Wiley & Sons, Inc., 1969.

J.K.N., Sackey, J.K.N., S.K. Amoaokohene, "Metalwork Technology", Macmillian, Reprinted in 2007.

R.D. Hirsrich, M.P. Peters, D.A. Shepherd, "Entrepreneurship" 6th Edition. McGraw Hill, (New Delhi) 2005.

Tarek Khalil, "Management of Technology": (The key to Competitiveness and Wealth Creation) McGraw Hill, 2000.