CHAPTER 2

PROPELLANT PREPARATION AND ROCKET CONSTRUCTION

2.1. INTRODUCTION

The propellant consistsof two ingredients of which one (sugar) can easily be melted at rather low temperatures. So it is possible to liquefy the propellant after heating to the melting point of sugar (177°C). At this temperature the sugar not only liquefies, but also decomposes into products that tend to lower the meltingtemperature of the mixture.

Potassiumnitrate, the other ingredient decomposes at 286°C losing oxygen to give the nitrites. It becomes liquid above 400°C. This means that the temperature should always be kept sufficiently lower than 286°C.

So we have in fact two reasons to keep the propellant temperature at low levels:

- preventing fast decomposition of sugar
- preventing decomposition of potassiumnitrate, and consequently autoignition.

After complete cooling of the mixture, the propellant becomes hard and strong. The propellant is than built up of a continuous sugar matrix and randomly destributed potassiumnitrate particles.

It will be shown later that the best propellant composition is in the neighbourhoud of 60% potassiumnitrate and 40% sugar. This mixture is also easy to manipulate, while higher concentrations of potassiumnitrate will give too high viscosity of the liquid. On the other hand, too low a potassiumnitrate concentration will make the liquid too fluid and can cause segragation of the solid particles.

It has already been mentioned that when sugar is heated it decomposes. When this happens the sugar turns from white to brown. This phenomena increases with temperature and time and will eventually make the mixture unuseful. This means that the whole procedure has

to be elaborated in a short time and with stirring in order to prevent regions with higher temperatures.

2.2. PREPARATION OF THE PROPELLANT

Before starting, sugar and potassiumnitrate have to be well dried and grained. Too large potassiumnitrate particles cause inhomogenities and may not be kept in solution when liquefied. Drying is very important because the propellant is very hygroscopic and any moisture will cause deviations in the burning rate and even misfiring. Therefore it is also important that after the propellant has become solid, it should be kept away from any moisture.

2.2.1. Initial preparation method

When we first started our experiments, the propellant was made by adding powdered potassiumnitrate to the molten sugar, while in the mean time the mixture was stirred. When all oxidizer was added, the propellant was poored into the rocket chamber where it cooled.

This procedure was rather slow and it was also very difficult to prevent degradation of the sugar.

2.2.2. Final preparation method

After some tests powdered potassiumnitrate and sugar were mixed together before heating. The propellant was than melted under contiuous stirring. Heating was done in an open electric kettle, normally used for friting. Heating was applyed till a good viscosity was gotten. During that period the colour of the propellant changed from white to light brown.

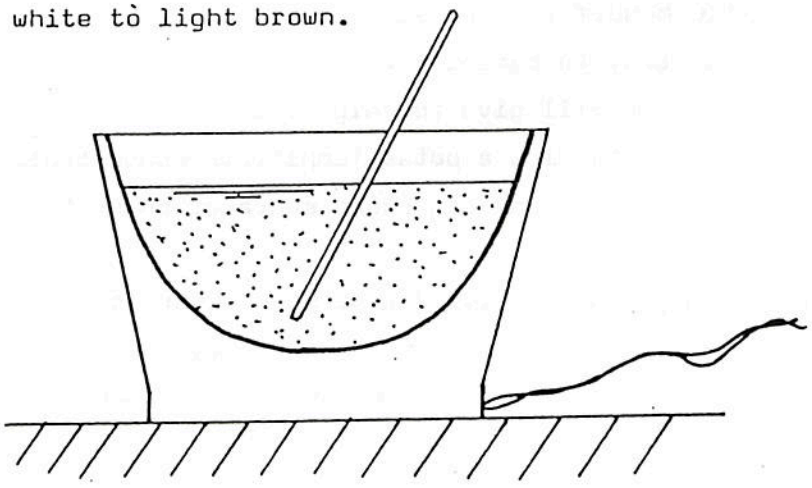


Fig.2.1. Melting the propellant.

Quantities of about 2,5 kg were prepared this way.

After liquefaction the propellant was poored into the rocket chamber where it slowly cooled and solidified.

It should be mentioned that temperature measurements indicated a decrease in melting temperature ones the sugar started to decompose. We normally worked at a temperature of about 135°C. To prevent overheating of the propellant, heating was done very slowly and the propellant was at all times well stirred.

2.3. PREPARATION OF THE COATING

To prevent burning of the propellant at unwanted surface, i.e. the contact area with the wall, the inner surface if the rocket chamber was coated. This was done with sugar or with a mixture of sugar and salt, normally in a 50/50 ratio.

The mixture was first liquefied , than poored into the preheated rocket motor and finally the rocket was revolved on a lathe in order to centrifugate the mixture. This procedure resulted in a nice coating of 2 to 2,5 mm thick.

It is important to know that a sufficient large quantity of mixture should be used, because otherwise the liquid will never reach the nozzle end of the chamber during centrifugation. This is of course due to the viscosity of the material. For instance we never succeeded in making coatings of 1 mm.

It is also very important to preheat the rocket before adding the coating material, since this prevents preliminary cooling.

Sometimes when pure sugar was used, the coating showed cracks after cooling. This doesn't mean that the coating cannot be used any more, because these cracks will disappear ones the propellant is added. Indeed, the coating material will again liquefy when it contacts the hot propellant.

One may ask why this type of coating was used, and not for instance materials like polyester. The reason is the following. When the propellant is added to the rocket chamber already coated with this material, it will heat up again the coating, and the sugar matrix in both propellant and coating will be the same. This means that this type of coating assures a profound contact and prevents any danger of burning of the propellant on those surfaces where it was applyed. Polyester can not fulfil the same role and is therefore useless for this purpose. However it is not excluded that other materials that stick very well - like some acrylics - could be used.

2.4. PREPARATION OF THE GRAIN

After the coating is applyed to the inner rocket wall, the chamber can be filled with propellant. This was always done by pooring the hot propellant directly into the chamber.

Different grain configurations and methods have been applyed:

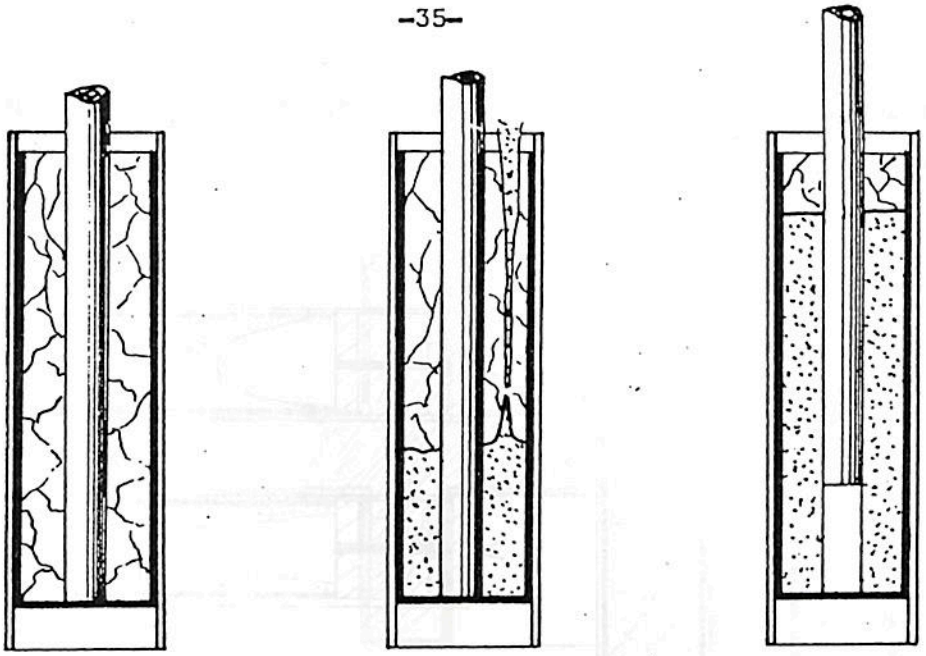
- cylindric perforation by casting;
- cylindric perforation by centrifugation;
- crucifix perforation by casting.

2.4.1. cylindrical perforation by casting

This type of rocket grain was made by putting a cylindrical rod in the centre of the chamber. The liquid propellant was than poored between rod and coating, till the rocket was filled with propellant up to the desired level. The propellant was than slowly cooled in order to prevent cracks. When the propellant had reached a state of high viscosity, the rod was withdrawn, and this was not so easy!

Normally a metal rod of 2,7 or 3 cm in diameter was used. Typical rockets fired along this procedure were: GX-6 to 11, GX-24 and GX-27.

This system however had two main disadvantages. At first it was



coated rocket with rod | filling with propellant | withdrawal of of the rod

Fig.2.2. Preparation of the grain with cylindrical perforation made by casting.

always difficult to withdraw the rod because the propellant was still soft and sticked to the metal. Secondly the burning surface was very rough and irregular. Other disadvantages like low density will be discussed later on.

2.4.2. cylindrical perforation by centrifugation

In order to increase the density and consequently to improve the mechanical strenght of the propellant, the method of centrifugation was used.

The rocketchamber provided by coating is filled with the necessary amount of propellant. The chamber is than closed with a plug in order to adjust the grain lenght. The rocket is than put on the lathe where it is turned around in order to centrifugate the propellant. The centrifugation has to last till all propellant has cooled to about 30 - 40°C. At this temperature the propellant is strong enough to withstand the deformation when it is released from the lathe.

It is clear that the size of the central hole depends upon the amount of propellant used and upon its density after processing.

The main advantage of this system is a more regular burning of the propellant and a much higher density.

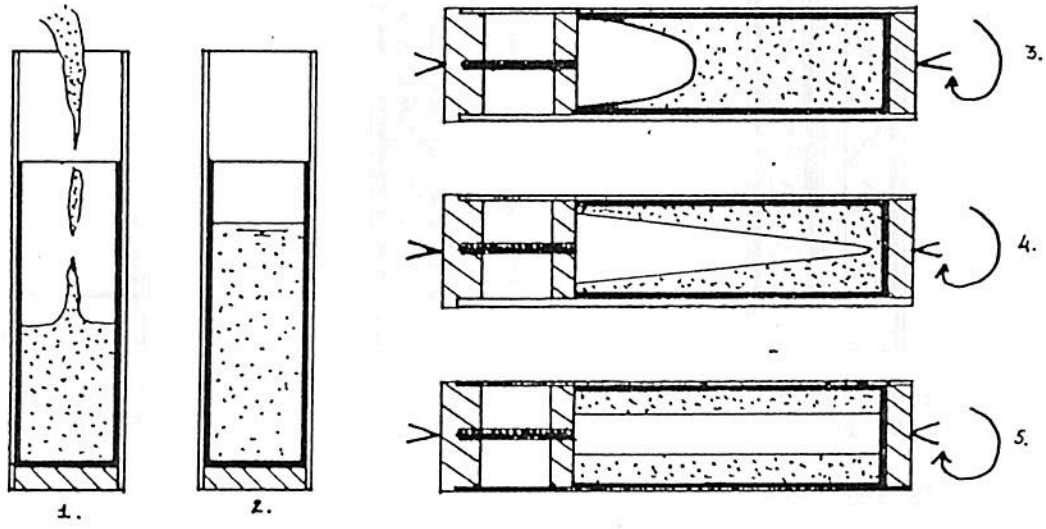


Fig.2.3. Different steps in the preparation of a centrifugated propellant.

It should be stated that this method needs some care. First of all too fast cooling of the propellant before the rocket is put on the lathe should be prevented, since this would lead to a conical hole instead of a cylindrical one. Fast cooling while centrifugating is also bad, since it will influence the density of the propellant because the air bubbles need some time to get from the inside of the propellant to the outside. With lower temperature the viscosity of the mixture increases and it will be more difficult for the air-bubbles to move.

It is obvious that the r.p.m 's play an important role. Normally we used about 700 r.p.m.

Typical rockets prepared with this method were: GX-60,NEBEL 1 - 5, NEBEL 11 - 13.

2.4.3. crucifix perforation by casting

To prevent the difficulties to withdraw the metal rod, and in order to try to realise less degressive thrust diagrams a crucifix core

was used. This mandrel was made of wood and covered with very thin alumina plating (fig.2.4.).

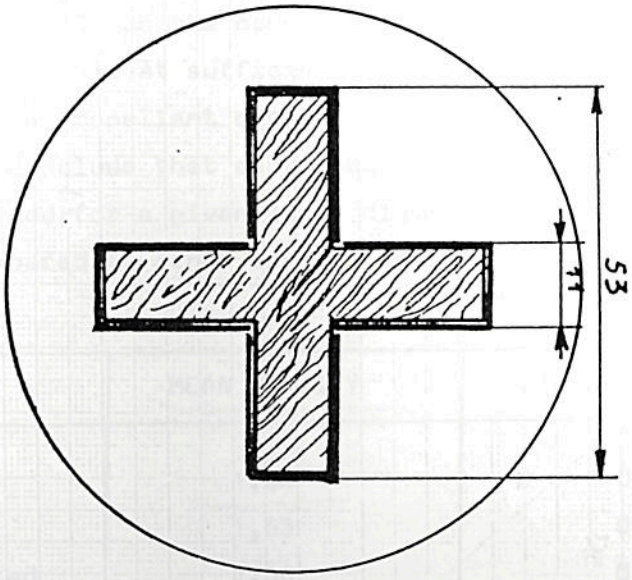


Fig.2.4. Drawing of the crucifix mandrel

After the inner chamber was covered with coating, the mandrel was positioned, and the propellant was poored into the chamber. The propellant was than left for a few days in order to cool to room-temperature. Before testing first the wooden mandrel was taken a-way - which was normally very easy since it was only in contact with the aluminum plates - than the aluminum plates were taken away. For this purpose the aluminum plates were first bended in order to ease the release from the propellant that has the tendency to stick.

Typical rockets made with this method were: GX-25 - 26,28,44, CANDY 1 - 4, NEBEL 6 - 10.

2.5. THE DENSITY OF THE GRAIN

The different preparation methods for the propellant grain had their influence on the density of the grain. This is shown in the next tabel.

Let us look now in more detail to the centrifugated grains. Figure 2.5. shows the density of the grain as a function of the inner dia-meter. It can be seen that there is a good relation between both.

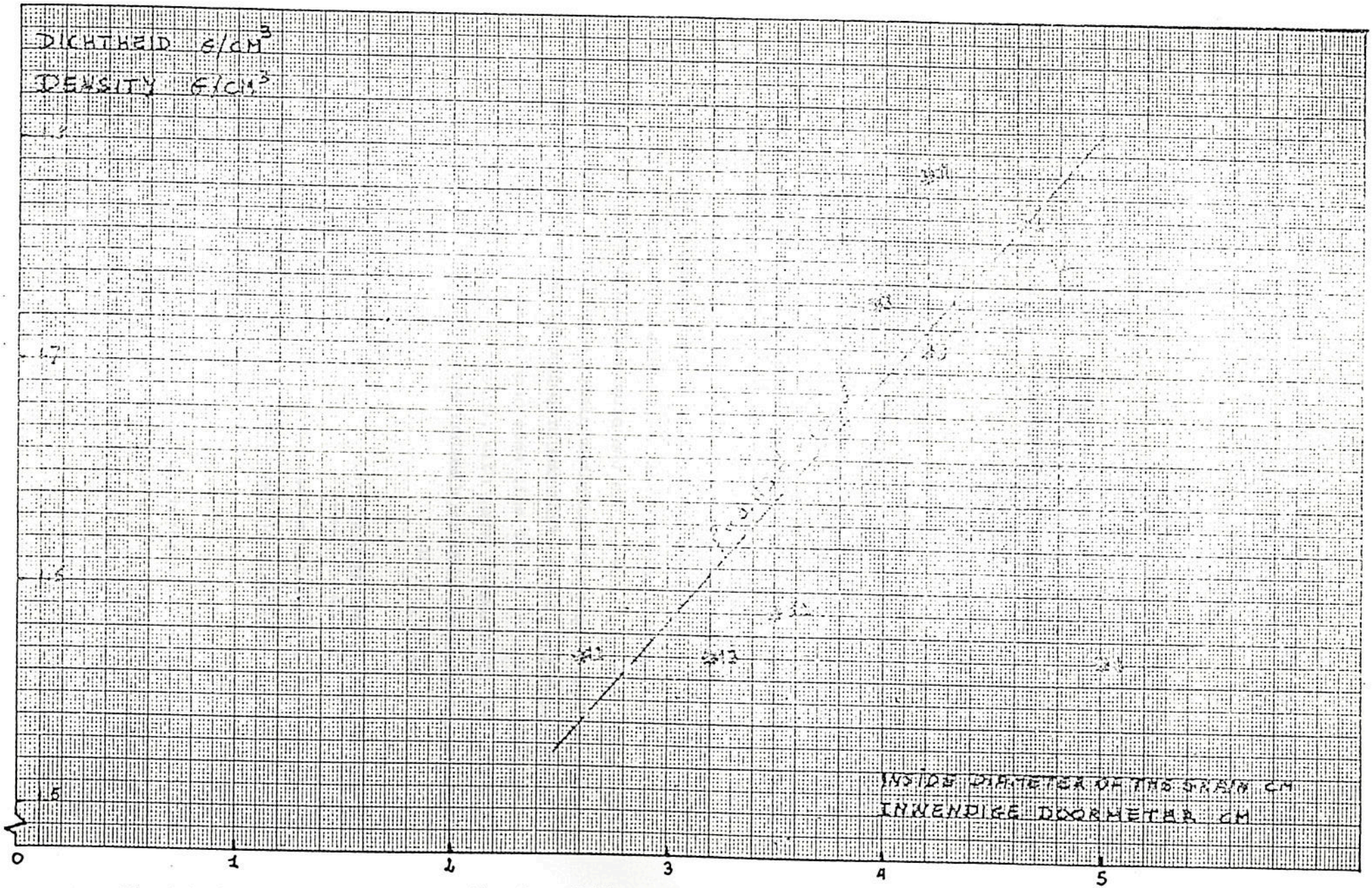


Fig.2.5. Influence of the inner diameter of the propellant on the density for centrifugated propellants

This result could in fact be expected since as the inner diameter increases the centrifugal force increases and so the force on the air bubbles, while on the other hand the air bubbles have less distance to travel. At sufficient large inner diameters (i.e. more than 4,5 cm) a propellant density of 1,75 g/cm^3 is achieved. From this we can conclude that centrifugation of the propellant increases the density and for a given inner diameter, the standard deviation is small compared to other ways of operation.

METHOD	MEAN DENSITY	STANDARD DEVIATION
all tests	1,64	0,11
casted	1,63	0,11
centrifugated	1,68	0,10
casted with crucifix	1,68	0,08
casted with cylinder	1,60	0,09

The worst results we got when the propellant was casted with the metallic cylindrical rod.

From the tabel one can conclude that casting with the crucifix core gave the same results as centrifugation.This however is not completely true, because the density in the case of centrifugated propellants also depends upon the inner diameter. What is given here is the main result, and does not reflect the very good results in larger diameters. However it shows that casting with the crucifix core was extremely good.

2.6. STORAGE OF THE GRAIN

Ones the rocket filled with propellant - or even with coating - the material must be kept away from any moisture, because it is very hygroscopic. For this purpose the inner space of the rocket was filled with silicagel - a very strong dehydrating agent - and the chamber was hermetically sealed to prevent any penetration of moisture. Normally plastic bags were used for this purpose.

2.7. DIAPHRAGM AND IGNITION

During the different tests, several types of diaphragms were used. The most common were:

- molten zinc and sulphur poored into the throat;
- 4 mm thick wooden plate.

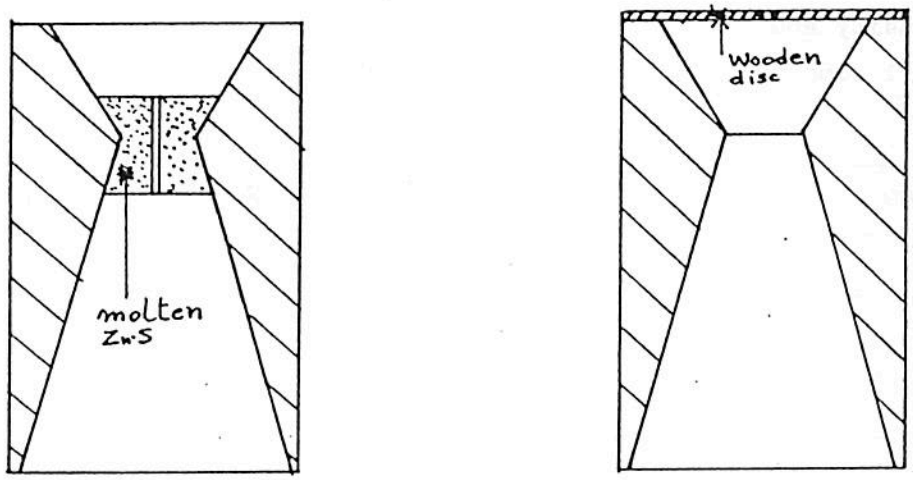


Fig.2.6. Different types of diaphragm.

Both types of diaphragm performed well, although in NEBEL 12 it was shown that the wooden diaphragm was blown against the nozzle wall, so that in fact we had some doubts whether this diaphragm did not obstructed the throat and caused the explosion.

The zinc and sulphur diaphragm that was used for a while, was left because we were convinced that this type could under no circumstances give enough reproduceability.

The igniter was put in the front end of the rocket, together with a small amount of powdered zinc and sulphur.

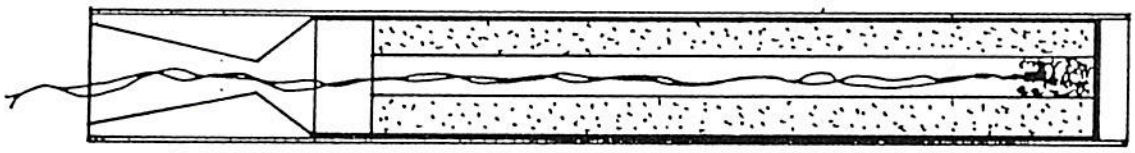


Fig.2.7. Position of the igniter and the ignition propellant.

Normally about 50 g of zinc and sulphur 2/1 was used. In some cases more zinc and sulphur was used, and we believe that this might have been one of the main reasons why these rockets exploded. In fact the amount of ignition propellant was purely emperically taken, and changes in the inner rocket volume were not taken into account.

2.8. CONSTRUCTION OF THE ROCKETS

Three different types of rockets were used for these tests. In the first type it was possible to change the throat area by replacing the middle part of the nozzle. This was done this way in order to be flexible. These rockets were called GX. (fig.2.8.).

A second type of rocket was CANDY. This rocket was designed for flight purposes. The front plate and the nozzle were screwed in the rocket chamber (fig.2.9 and 2.10).

The third one was called NEBEL and was built by NERO. This rocket had a larger inner diameter than the previous ones. Front plate and nozzle were fixed by bolts (fig.2.11).

It should be noticed that in the diffent tests almost no attention was payed to the shape of the nozzle. Depending upon the test the throat was sometimes increased by drilling a bigger hole. This means that sharp edges occured giving lower nozzle efficiencies.

In GX and NEBEL rockets, ordinary steel was used for nozzle,chamber and front plate. In the CANDY rockets, the chamber was made out of stainless steel. The wall thickness in the tree cases were:

GX : 4,5 mm

CANDY : 2 mm

NEBEL : 3,5 mm

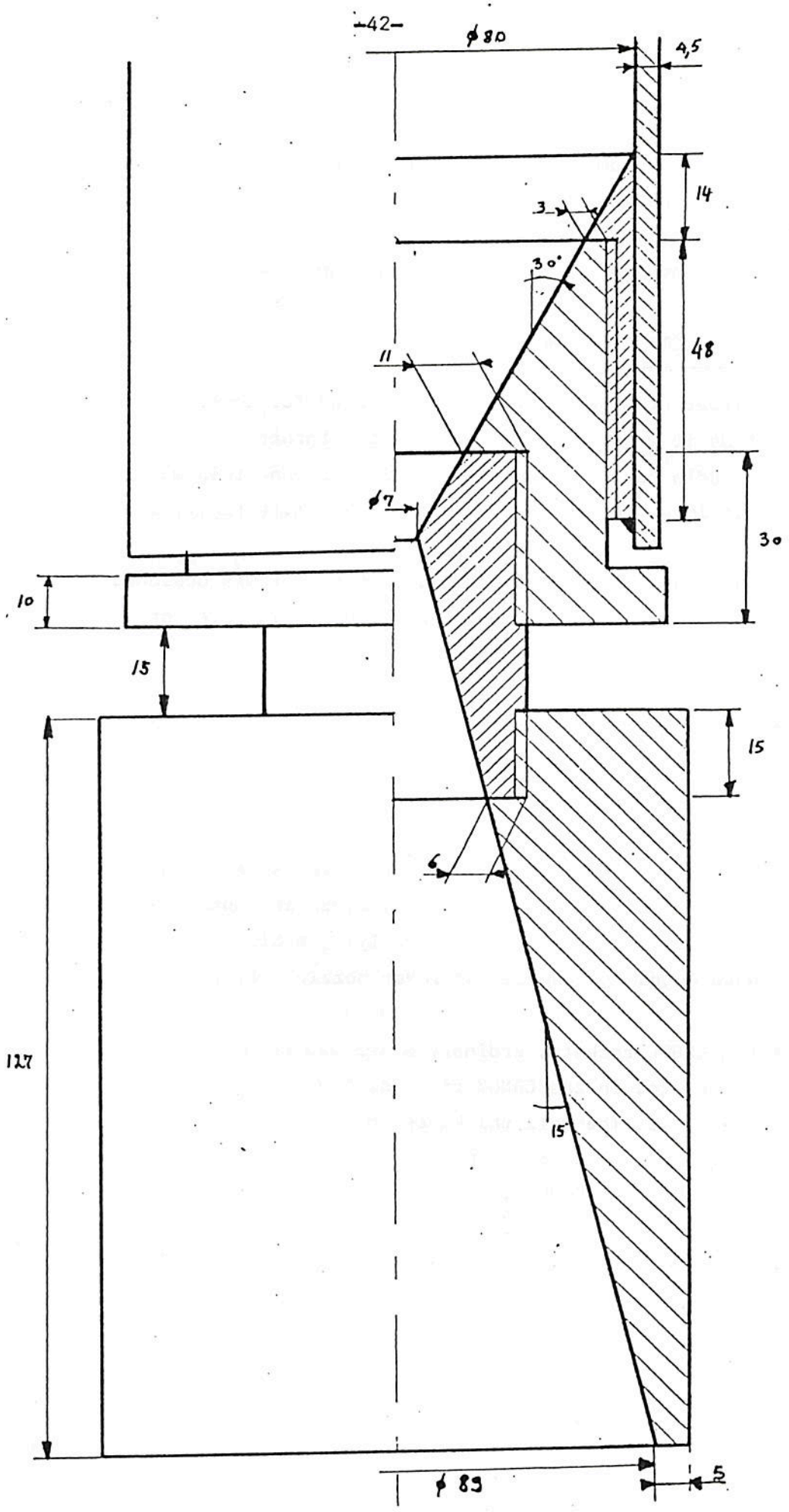


Fig.2.8. Construction of the nozzle used in the GX-rockets

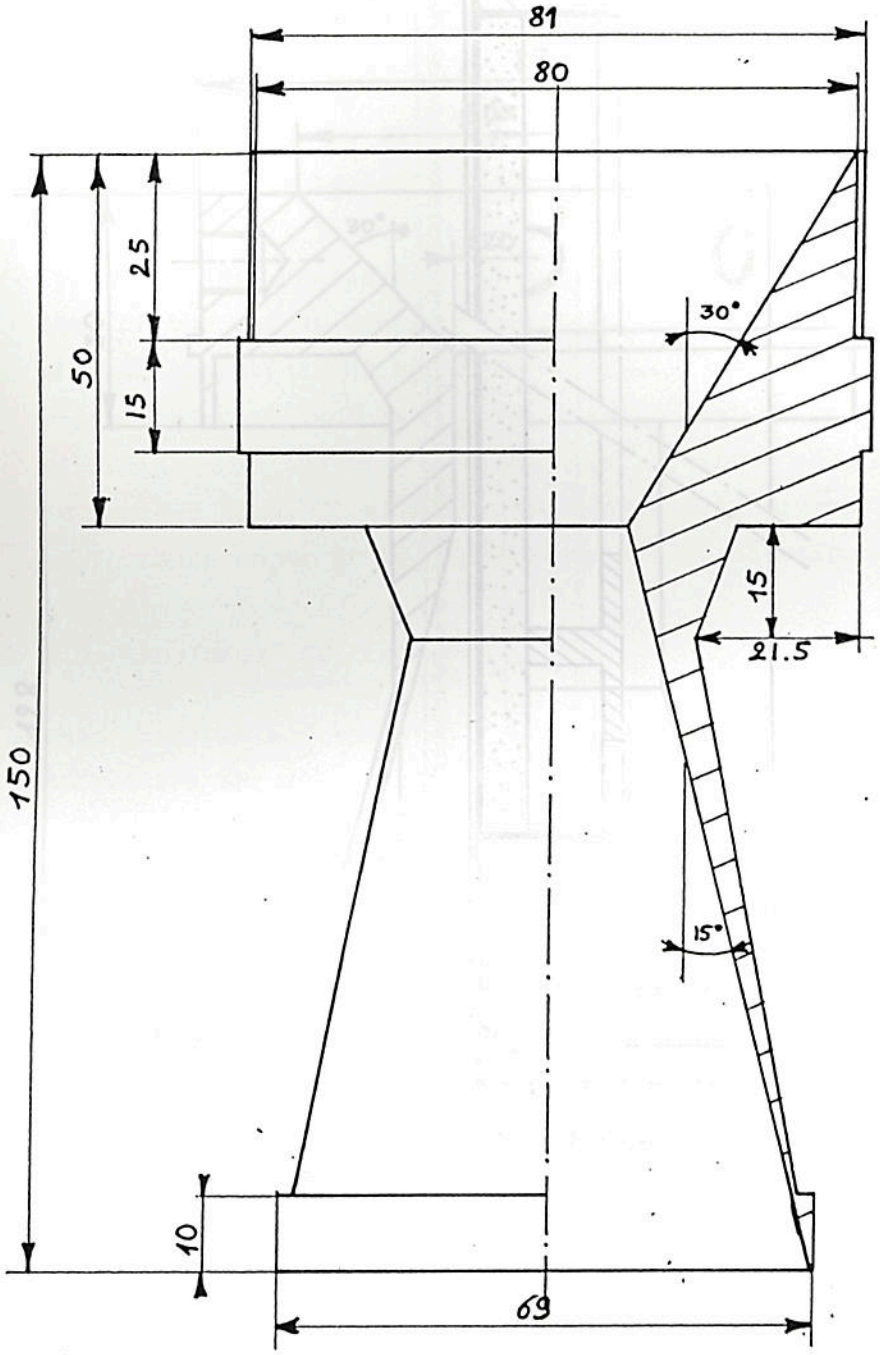


Fig.2.9. Nozzle used in the CANDY rockets.

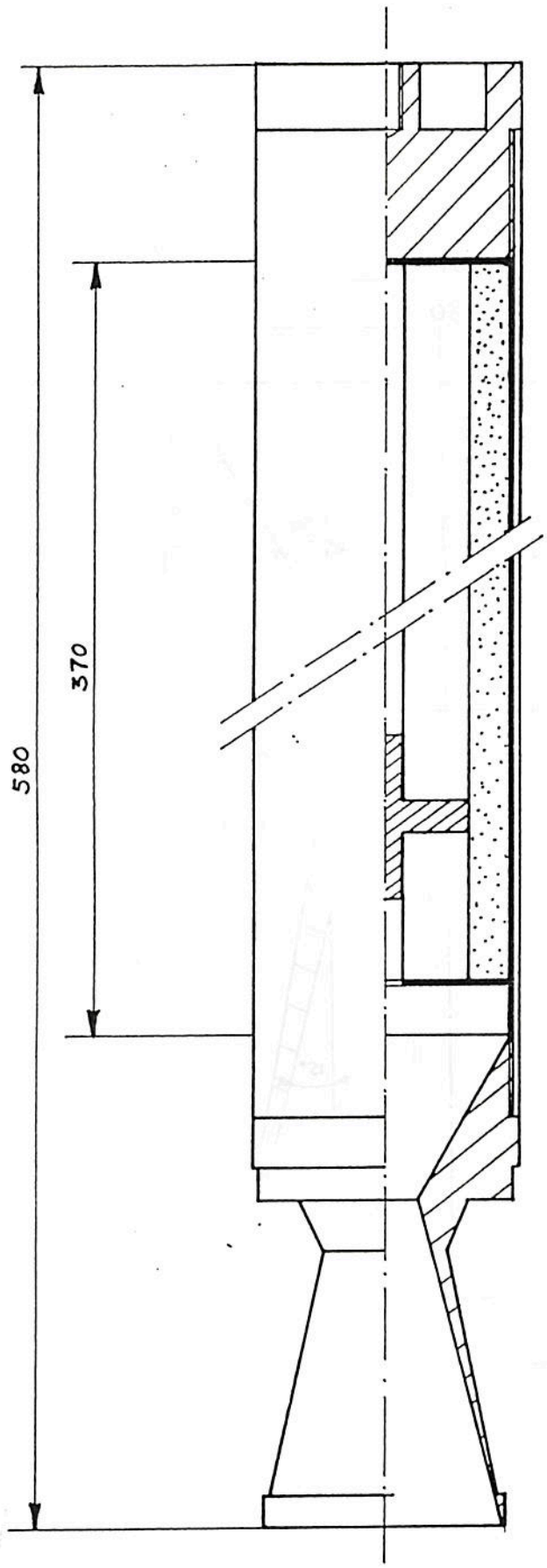


Fig.2.10. Composition of the CANDY rocket.

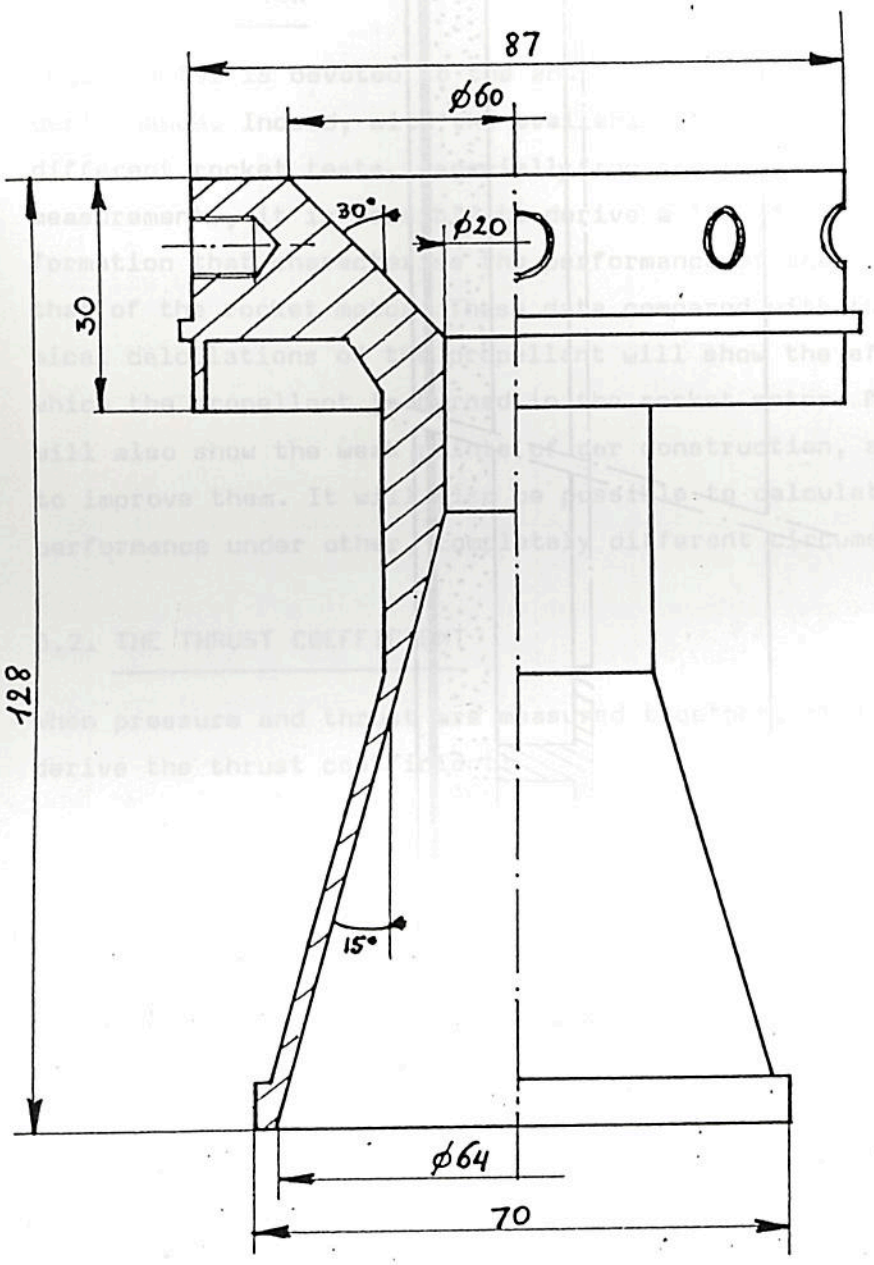


Fig.2.11. Nozzle used in the NEBEL rockets.

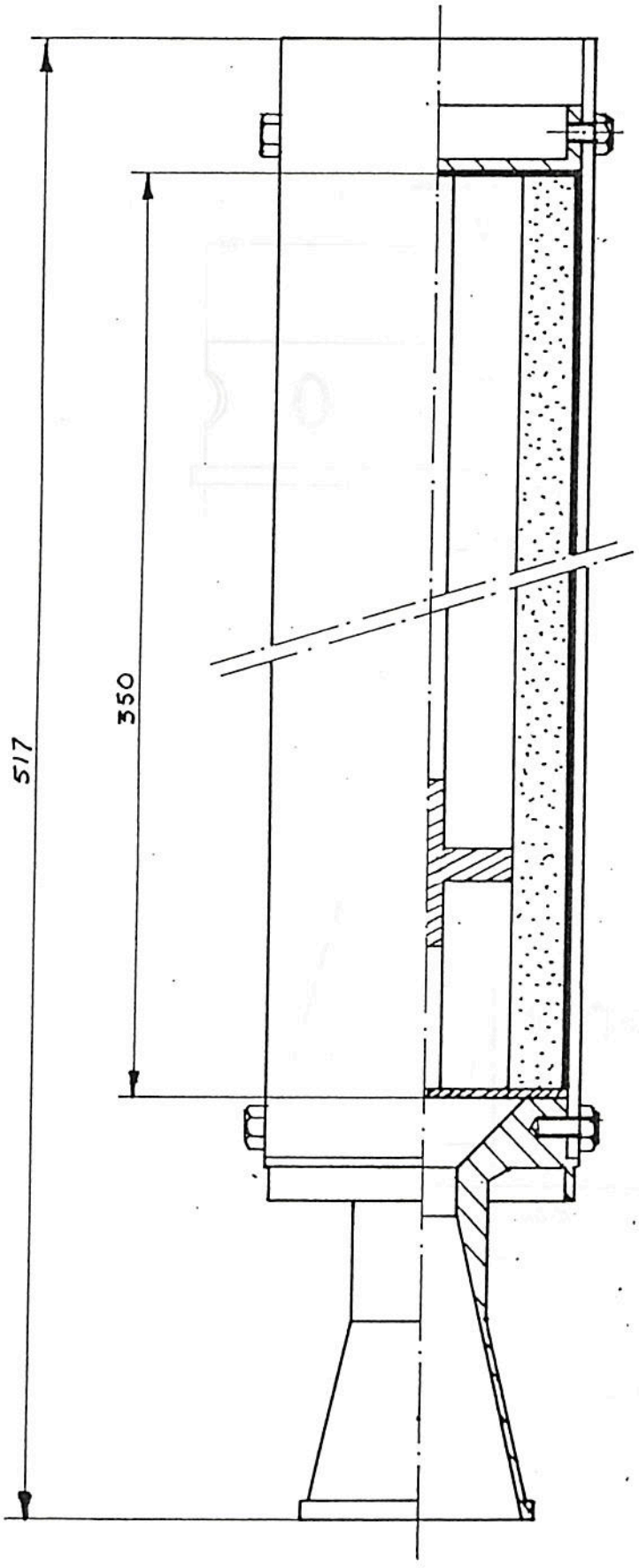


Fig.2.12. Composition of the NEBEL rocket