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# TWIN SCREW EXTRUSION FOR THE PRODUCTION OF STICK PROPELLANTS

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## ABSTRACT

The production of stick propellants is currently undergoing refinements in the pre-extrusion stage as well as the downstream handling and testing. The Fraunhofer-Institut für Treib-und Explosivstoffe (ICT) at Karlsruhe, West Germany is processing double base stick propellants, a "Gudol-Propellant" and a nitramine RDX, nitroguanadine and "Kraton" gun propellants. The results of the initial processing runs are reported.

The processing uses a Werner & Pfleiderer (WP) twin-screw extruder, one with double flighted screws (Continua) and a similar type with triple flighted screws (ZSK). The ZSK model has less free volume and therefore subjects the propellant to a higher shear and stress at the same screw speeds. The Continua model with the two flighted screws possesses a better feeding characteristic, is more gentle on the process material, and uses less drive power because of the reduced torque. The interchangeable screws and modular design of these extruders permit versatility in processing and facilitates the optimizing of mixing parameters.

Each extruder can be fitted with different dies or extruder heads to form and shape the extrudate--sticks. These sticks are then tested for ballistic properties and then modified to meet the special conditions for each propellant type. While these test materials met the performance objectives, the program will continue to incorporate various recipes under changing mixer configurations to obtain superior ballistic characteristics.

## INTRODUCTION

For the manufacture of stick propellants, the use of an extruder in a continuous process offers considerable advantages when compared to a discontinuous or batch process using mechanical rolling machines and hydraulic extruding presses. The extruder process (Fig. 1), while simplifying the work procedure, produces a more homogeneous, better mixed and more plasticiable product than that through conventional methods and improves the ballistic properties of the final product.

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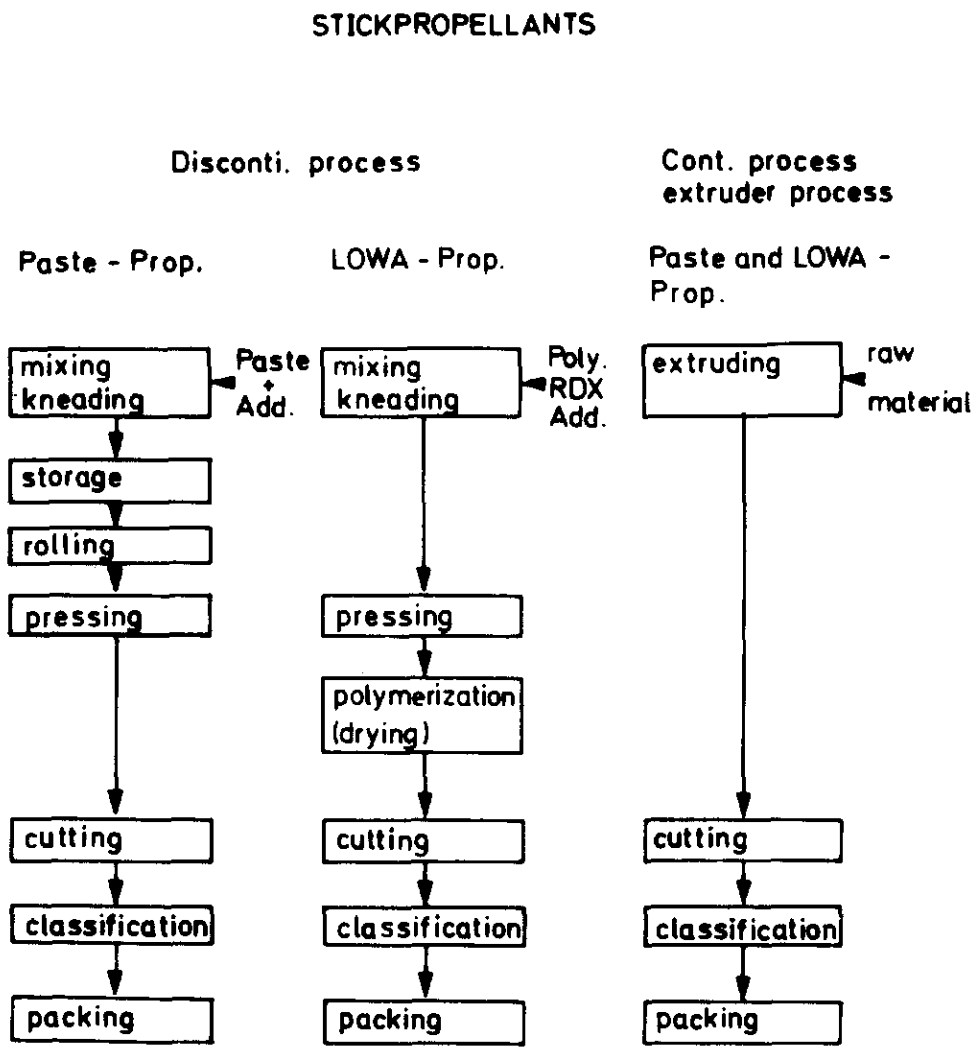


Fig. 1. Comparison of the discontinuous/batch process and the continuous process using the extruder for stick propellant production.

Apart from producing a reduction in operating personnel and saving costs of nearly 50%, the extruder process also provides advantages in safety, since the inventory of material in work is drastically reduced while the system's capacity remains the same. In a batch process, a large quantity of material is mixed for many minutes whereas a small quantity is intensively mixed for one or two minutes in the continuous extruder process. The inventory of active material in the extruder at any point in time is very small. The modular co-rotating, synchronous, twin-screw extruder manufactured by Werner & Pfleiderer is used for the development and manufacture of double-base paste-propellant (solventless), LOVA propellants. The forming die is always adapted to the rheological behaviour of the materials in process.

The Modular Co-Rotating Intermeshing Twin-Screw Extruder

The mixing and kneading extruder consists of several screw barrels which can be arranged lengthwise to permit a process line of any desirable length (Fig. 2). This extruder has the advantage that not only gun propellant in the solvent process (M30) but also water-wet NC/NG paste can be plasticized. A special dewatering design was developed to accommodate water removal (Fig. 3).

This twin-screw extruder has kneading and mixing facilities, as can be seen in the working principle and the movement of product between the kneading sections (Fig. 4).

The screws are located inside barrels with an 8-shaped bore, which can be either heated or cooled. Adaption of the geometrical shape of the screw to the processability of the propellant mass required is in conformance with the fact that the screws (Fig. 5) consist of conveying and kneading elements which are variable and exchangeable to different configurations.

"Dead spots" above from the saddle or at the screw base are not possible. Because of the unique staggering angle, the kneading elements with right staggering angle will convey the material axially downstream, whereas with a left staggering angle, it is partially conveyed backwards and causes a back-pressure.

The extruder barrels can be equipped with exchangeable wear liners (modular parts or inserts). In fact, thanks to such exchangeable wear liners, it is possible to operate the twin-screw extruder system not only with two-point elements, but also with three-point elements as well and still avoid dead spots (Fig. 6). The machine with the three-point (3-lobs) elements or the two-point elements with a higher curvature is a modified Continua, a ZSK type (Fig. 7). The three-point system permits a technically stronger design for the screw shafts (higher torque), thus allowing for a greater rotary force (shear) and a higher casing pressure. In addition to this, greater shearing and a more intensive kneading and mixing force is imparted to the material through the closer axial spacing of turns (pitch) in the conveyor sections (screw elements) and their different profiles. For super sensitive materials, the two-flighted screw configuration is preferred because of the decrease in shear force.

By changing the combination and design of the conveyor screw and kneading elements, including their staggering to left and right, by using two-point or three-point elements, as well as by taking advantage of the resultant curvature (profile of the kneading elements, Fig. 7), thus changing the compression surfaces of the kneading blocks, it is possible to achieve optimal adjustment to the material and products to be processed. In this way, double-base and LOVA propellants can also be extruded in a problem-free manner. Figure 8 shows the flow conditions in the processing sections.

We have found out that, in the manufacture of stick propellants, double-base (NG and NC) and RDX/Nitroquanidine/Kraton, the two-point element configuration provides optimum processing conditions. With the two-point profile, the following characteristics are obtained:

- good intake capacity,
- high output rate, and
- gentle treatment of material.

Processing of Stick Propellants

To manufacture stick propellants, the screws of the extruder are arranged so that kneading blocks with a left staggering angle as well as with a right staggering angle are positioned one after the other, separated by concave section of conveying elements on a process line of 21 diameters (777 mm) with a screw diameter of 37 mm (1.4567"). The screw elements in the feeding section may not only consist of concave section elements, but also of box section elements as well (Fig. 9).

The pressure at the die is approximately 80-90 bar/8-9 MPa and the rotary speed of the screws between 100 and 110 RPM.

The feeding into the extruder can be varied according to the ingredients. One example is Figure 10. A typical die is also shown in Figure 11.

The 120 mm stick propellant produced with DEGN had the composition shown in Table 1. The LOVA stick propellant was made with the composition shown in Table 2. The final extruded products are illustrated in Figure 12.

TABLE 1: DEGN Stick Propellant for CAL. 120x570 mm

| | |
|---|---|
| GP Type | I5420 / I5421 |
| Stick Length | 350.0 mm |
| Stick Diameter | 6.1 mm |
| NC (13.1% $N_2$) | 62.50 wt% |
| DEGN | 36.70 wt% |
| Centralite I | 0.25 wt% |
| Akardite II | 0.45 wt% |
| Other Components | 0.10 wt% |
| Explosion Heat | 4290 Joule/g |

TABLE 2: LOVA Stick Propellant

| | |
|---|---|
| Stick Length | 349.0 mm |
| Stick Diameter | 5.9 mm |
| RDX | 70 wet-% |
| Nitroguanidine (Picrate) | 15 wt% |
| Kraton and other Comp. | 15 wt% |

By means of a cutting machine and gripper feed specially developed at ICT, the strands are cut to measure for producing propellant grains. This procedure eliminates an elaborate sieving process (classification).

The gun propellant obtained, after the drying process, has a grain density which is at the top level or even higher as that conventionally manufactured M30 (Table 3).

TABLE 3: Properties of Dry Propellant M30E

| | |
|---|---|
| Propellant Type | M30 |
| Grain Length (mm) | 20 |
| Grain Diameter (mm) | 8.4 |
| Needle Diameter (mm) | 7x1.0 |
| Density (G/CCM) | 1.68-1.70 |
| Shrinking Factor (%) | Approx. 10 |
| Explosion Heat (J/G) | 4080 |
| NC (%N) | 12.45 |
| $\overline{M}_w$ | 600,000 |
| $\overline{N}_n$ | 100,000 |

Processing of M30 with Kraton

To manufacture M30 EK, the procedure is exactly the same as described above. Kraton binder is fed into the extruder so that the nitrocellulose is plastified first and the Kraton functions are an additional binding agent. We have restricted these additional quantities to 2-5 wt%.

RESULTS

Stick Propellant of the M30 Type

Using the "Continua", a seven-perforated propellant M30E and, with Kraton, an M30EK is manufactured in such a way that the propellant in question possesses better mechanical properties and also exhibits a more favorable brittleness behavior than with conventionally manufactured (standard) M30.

Therefore, the decrease in molecular weight of nitrocellulose determined by the processing conditions employed, as established using gel permeation chromatography (GPC), is less in extruded sticks than that manufactured conventionally with hydraulic presses. For example, a nitrocellulose having an $\overline{M}_w$ = 600,000 decreases to 430,000 with the extruder and in the pressing process to 340,000 to 320,000. This difference may result from the influence on mechanical brittleness due to the processing technique used.

The brittleness behavior is determined by the transmission of a short-term mechanical compression force to the grains. The stress time (a few seconds) is performed with the piston speed determined at 1.5 meters/second. These compressive strength trials are performed with stick propellant at different temperatures. As long as the propellant material retains its viscoelastic behavior, the compressive strength increases as temperature decreases. The addition of Kraton (2-5 wt%) resulted in no noticable change in the mechanical properties of the material.

However, long-term trials over 35 hours have shown that the addition of

Kraton causes an improvement in web homogeneity.

Inside the extruder, the pressure and temperature profiles can be designed for the particular composition to be extruded. A typical profile is presented (Fig. 13).

The extruders shown are fabricated by WP in both Europe and the U.S. and have interchangeable parts. A summary of the twin-screw extruder features are listed in Table 4.

TABLE 4: Twin Screw Extruder Features

| | |
|---|---|
| Co-Rotating Screws | - Positive Displacement |
| | - Self Centering |
| | - Self Wiping |
| Modular Barrels | - Adaptable to various processes |
| | - Feed, vent, devolatilization, extruding |
| | - Cooling and/or heating |
| | - Individual termperature control |
| Extruder | - Variable speed ratio |
| | - Construction materials - steel, bronze |
| | - Throughput lbs. to tons/hr. |
| | - Small inventory of material |
| | - Easily disassembled for cleaning |
| | - Mixes, evaporates, homogenizes, extrudes |
| | - Totally enclosed (no fumes) |
| | - Remotely operated |
| | - Batch or continuous operation |
| | - Automatic |
| | - Proven in operation |

The continuous process has been demonstrated in small production lines and in the laboratory in Europe. The small production rate is now ready for scale-up and the feasibility to produce LOVA and stick propellants is proven in the R&D laboratories.

The ICT facility is preparing to install a higher capacity extruder. This larger extruder will permit an accurate scale-up for the production line extruder (Fig. 14).

The program is continuing at ICT to produce propellants with superior characteristics. Combining the experience of Werner & Pfleiderer with the twin-screw extruder in the food, plastics and rubber industries, and the experience of ICT with explosives and propellants, the processing technology is advancing in an orderly and safe manner.

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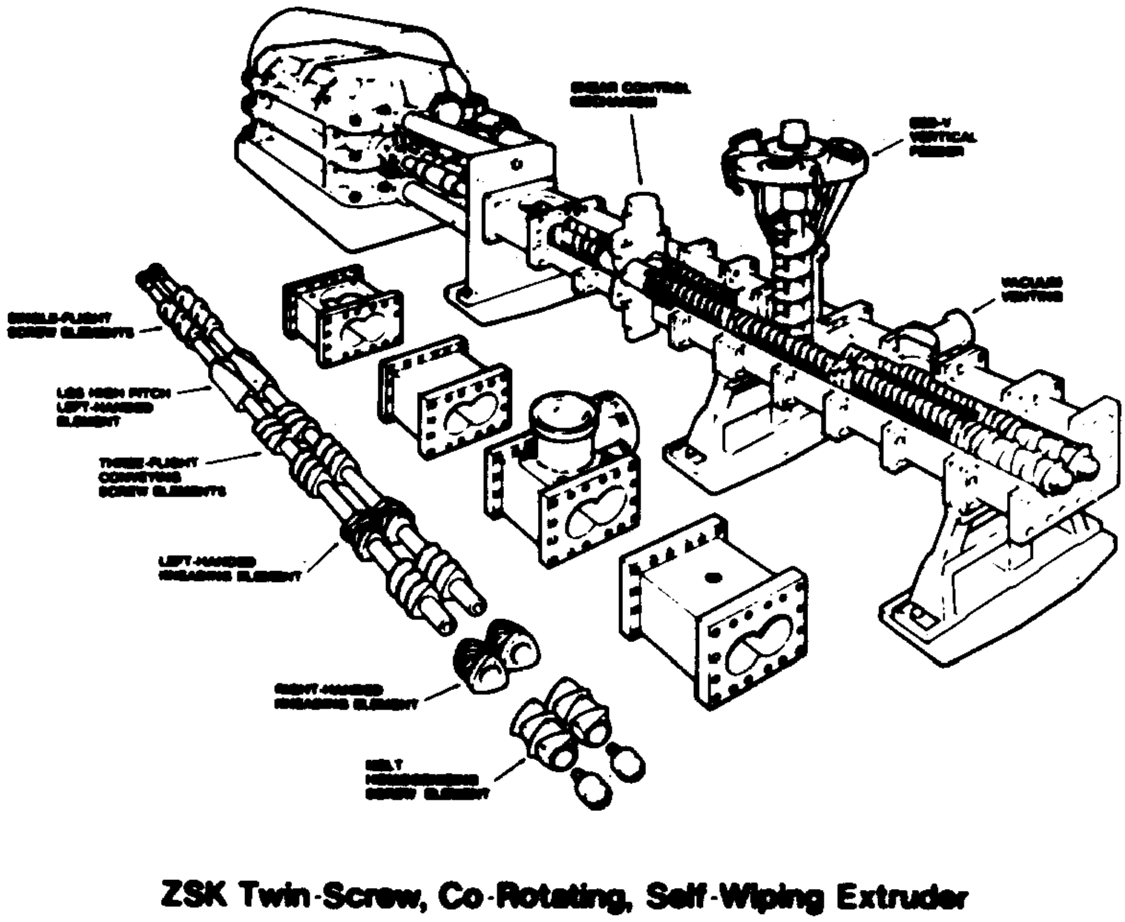



Fig. 2: Modular Extruder Design

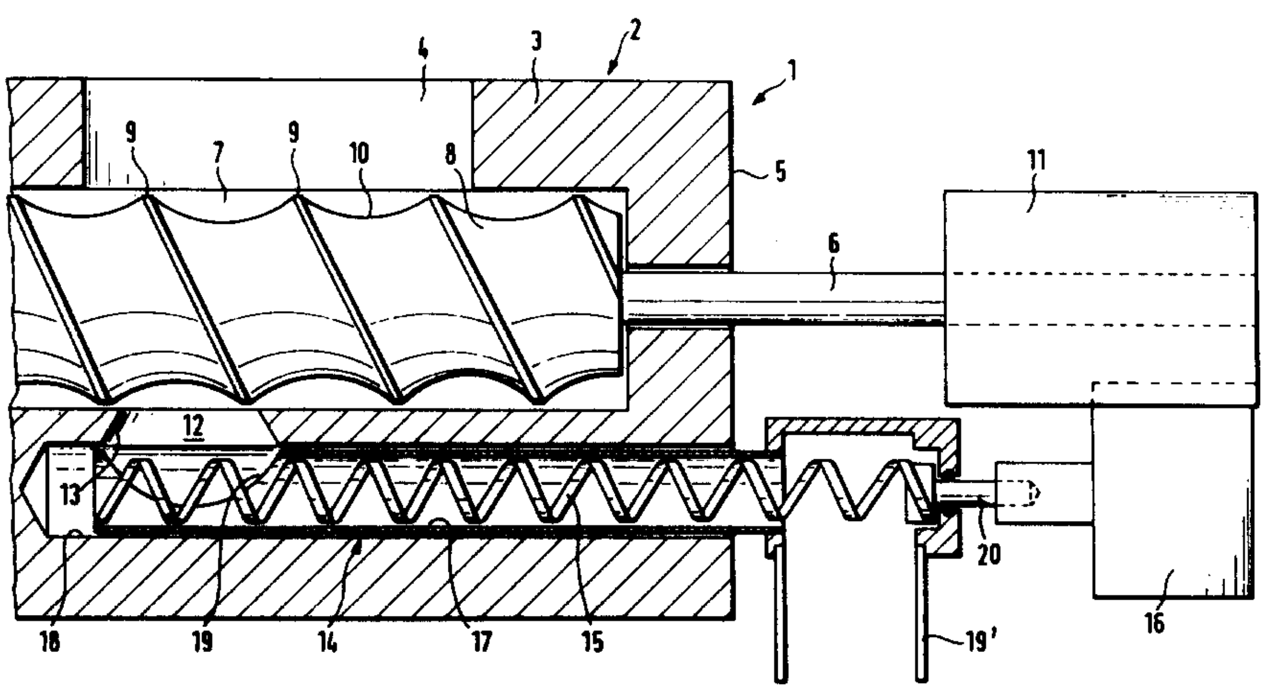



Fig. 3: Special Dewatering Screw with Screen and Vacuum in Extruder Feed Section.

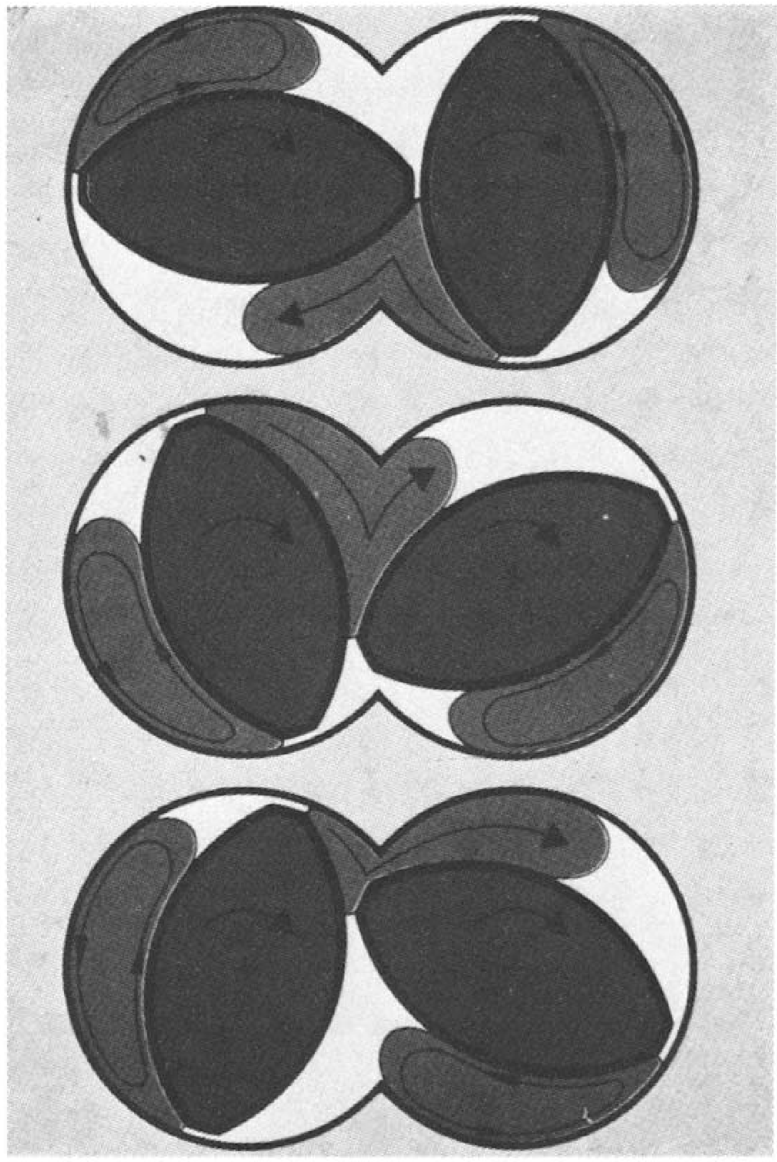


Fig. 4: Flow of Material Between the Two-Flighted Kneading Elements

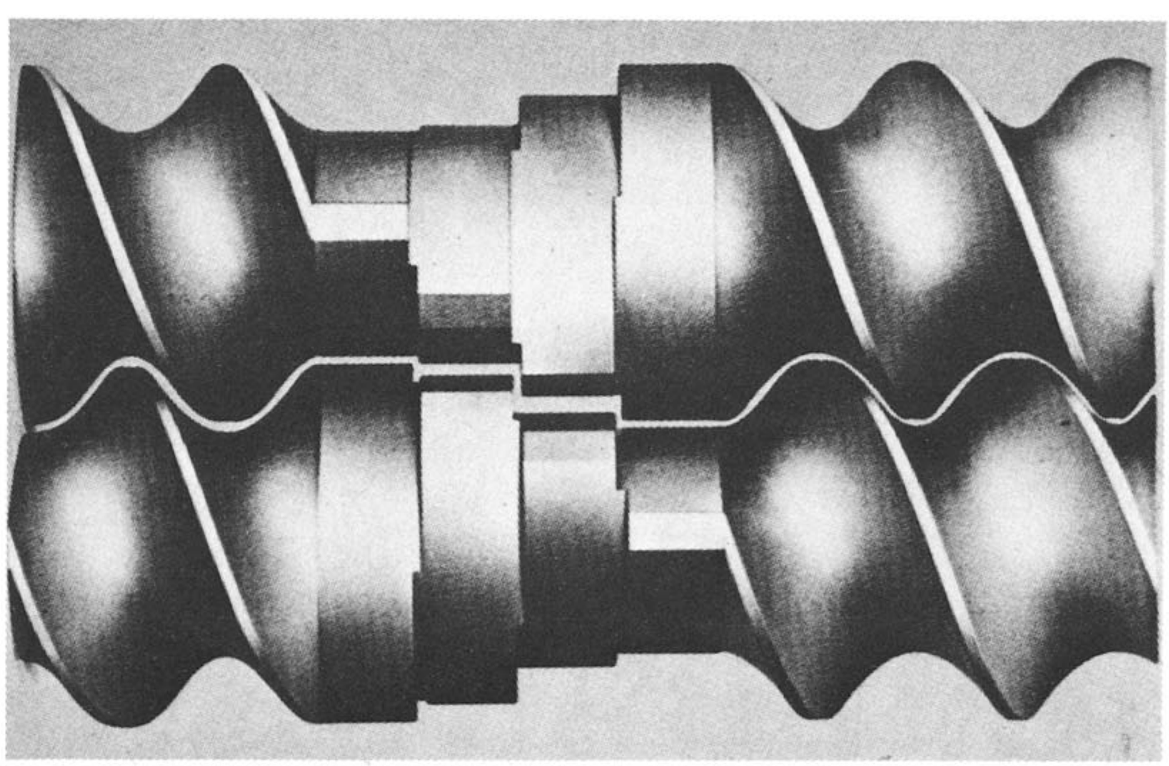


Fig. 5: Profile of the Self-Cleaning (Self-Wiping) Screw and Kneading Elements

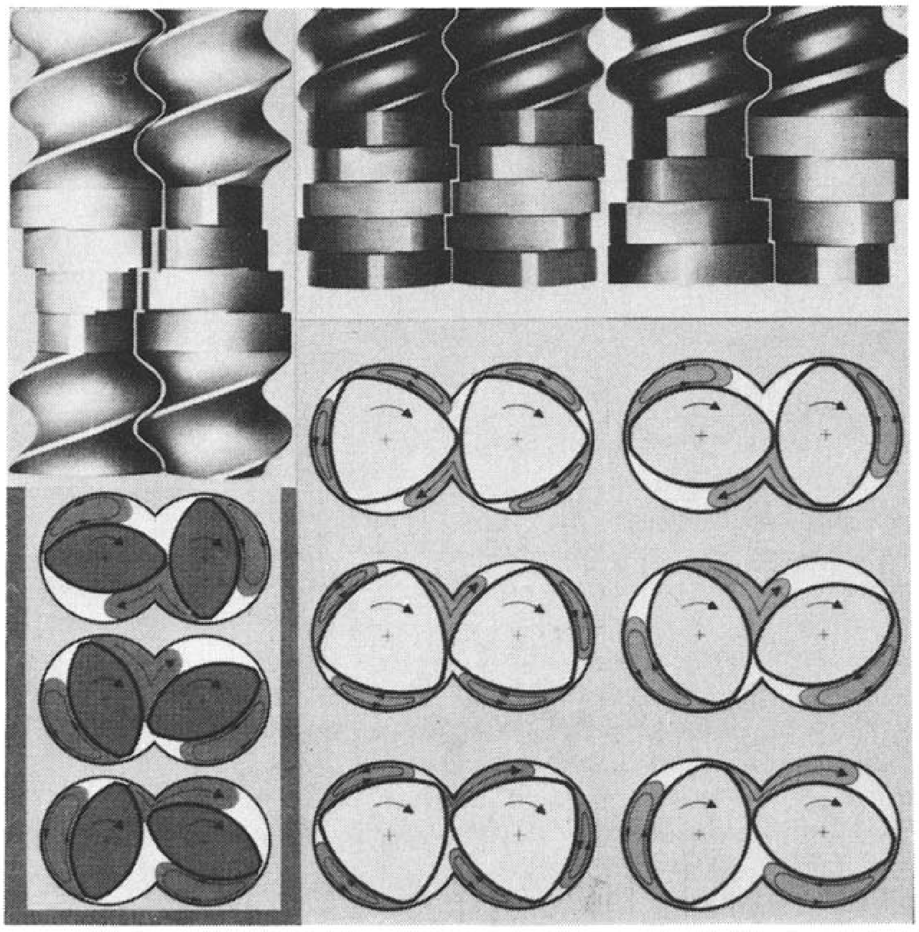


FIG. 6: Twin - Screw Extruder Operating Mode

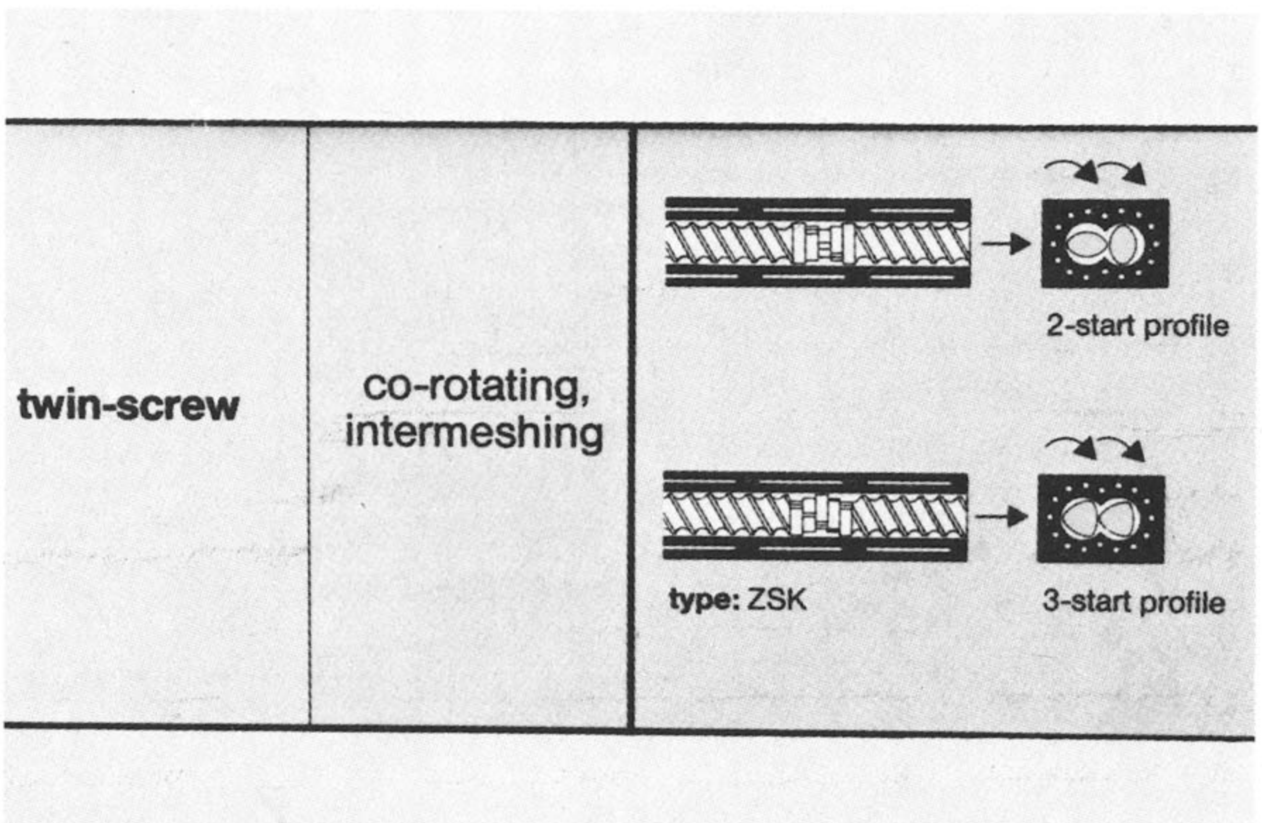



Fig. 7: Comparison of Material Flow Between Two-and Three-Flighted Profiles in a Continua and ZSK Type Extruder

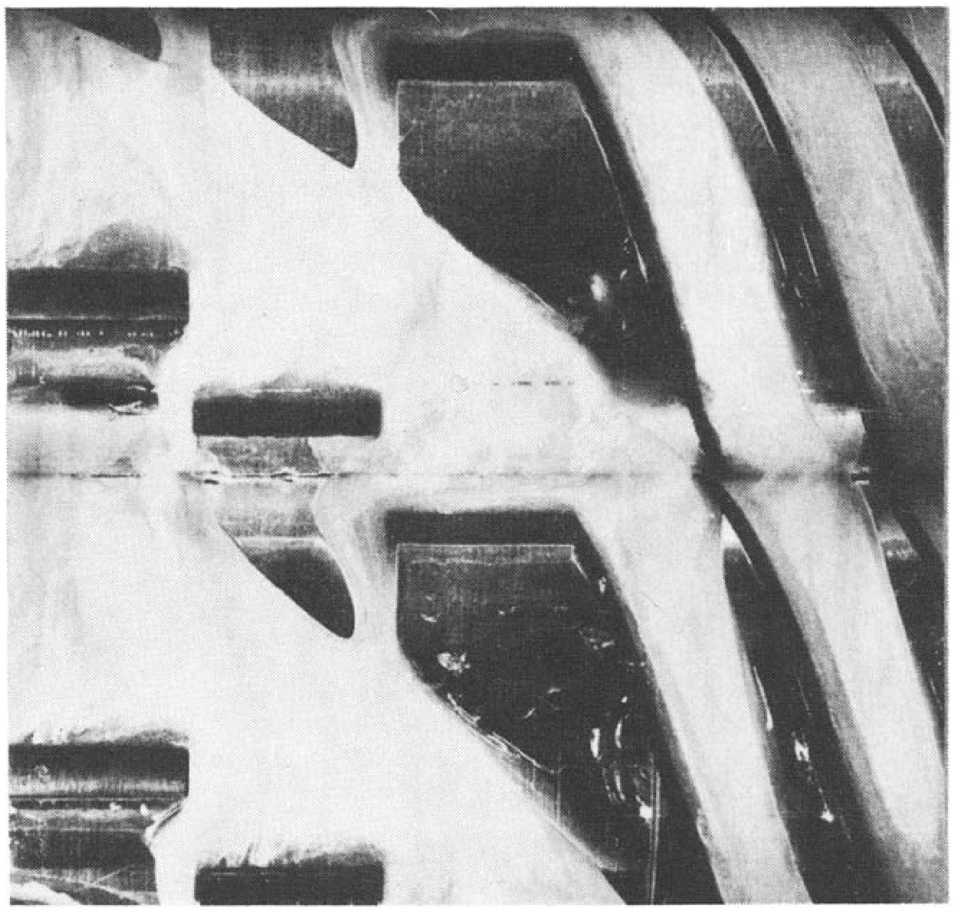


FIG. 8: Typical Flow Conditions in the Process Section of the Co-Rotating Twin-Screw Extruder

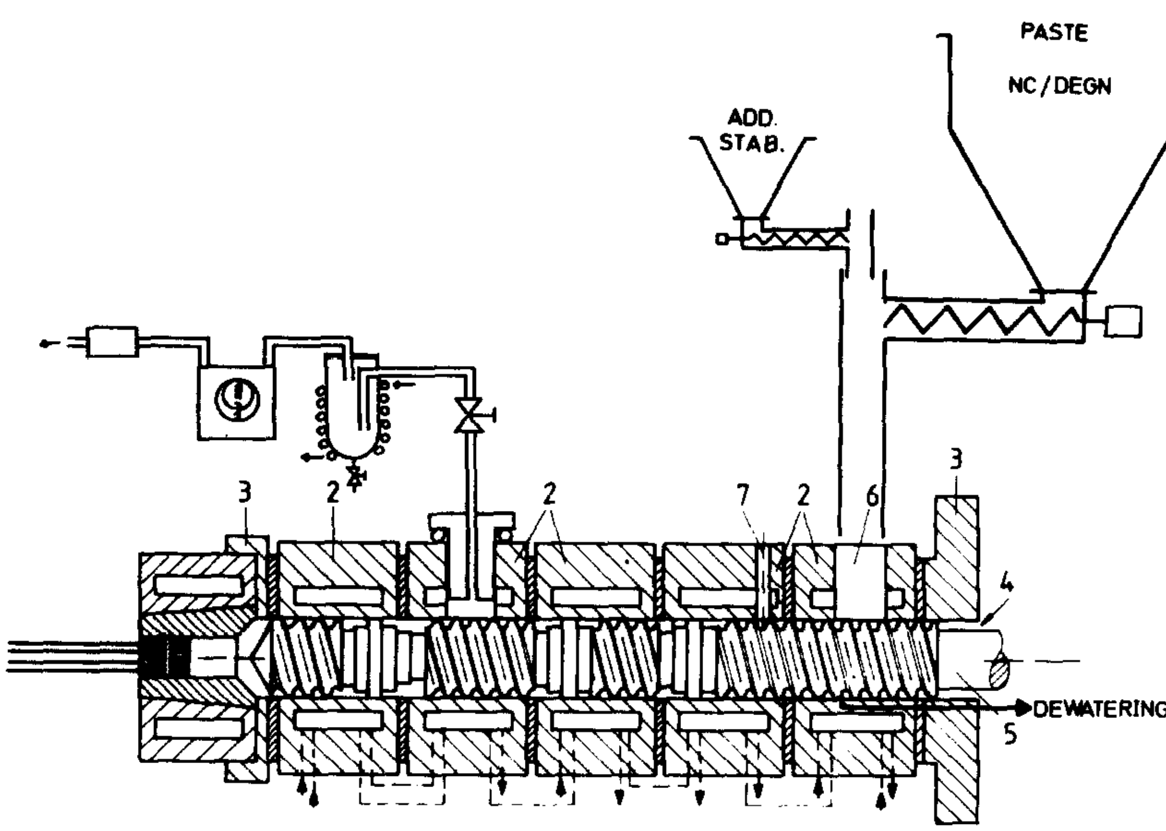



FIG. 9: Confirguation for Stick Propellant with Feeding of Paste and Additives in One Feed Section. Dewatering of Water-Wet Paste by Dewatering Screw and Vacuum

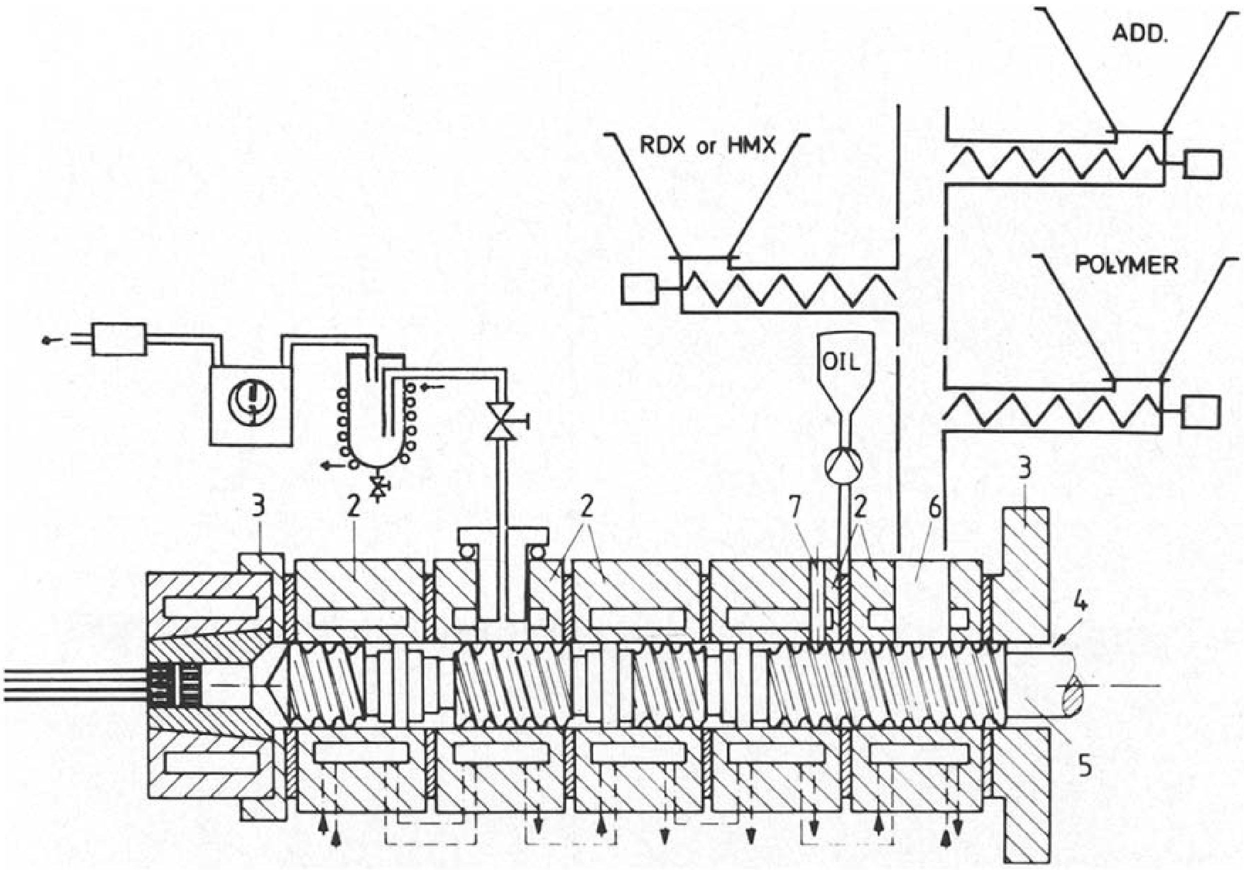



FIG. 10: Configuration for LOVA Type Propellant. Polymer (Kraton) is fed concurrently with RDX or HMX. Any oil plasticizer is injected downstream. Vacuum is applied before extrusion.

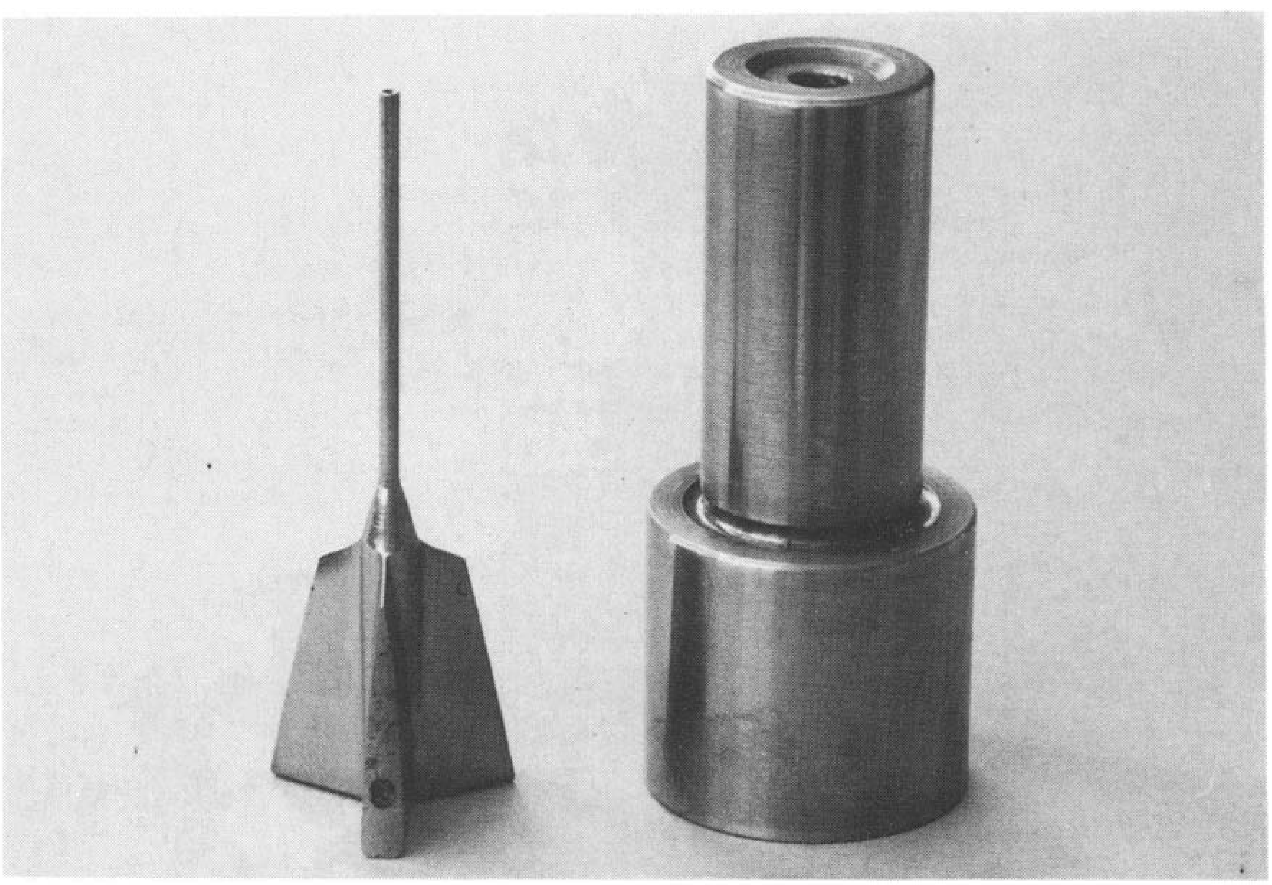


FIG. 11: Production Die for Stick Propellant

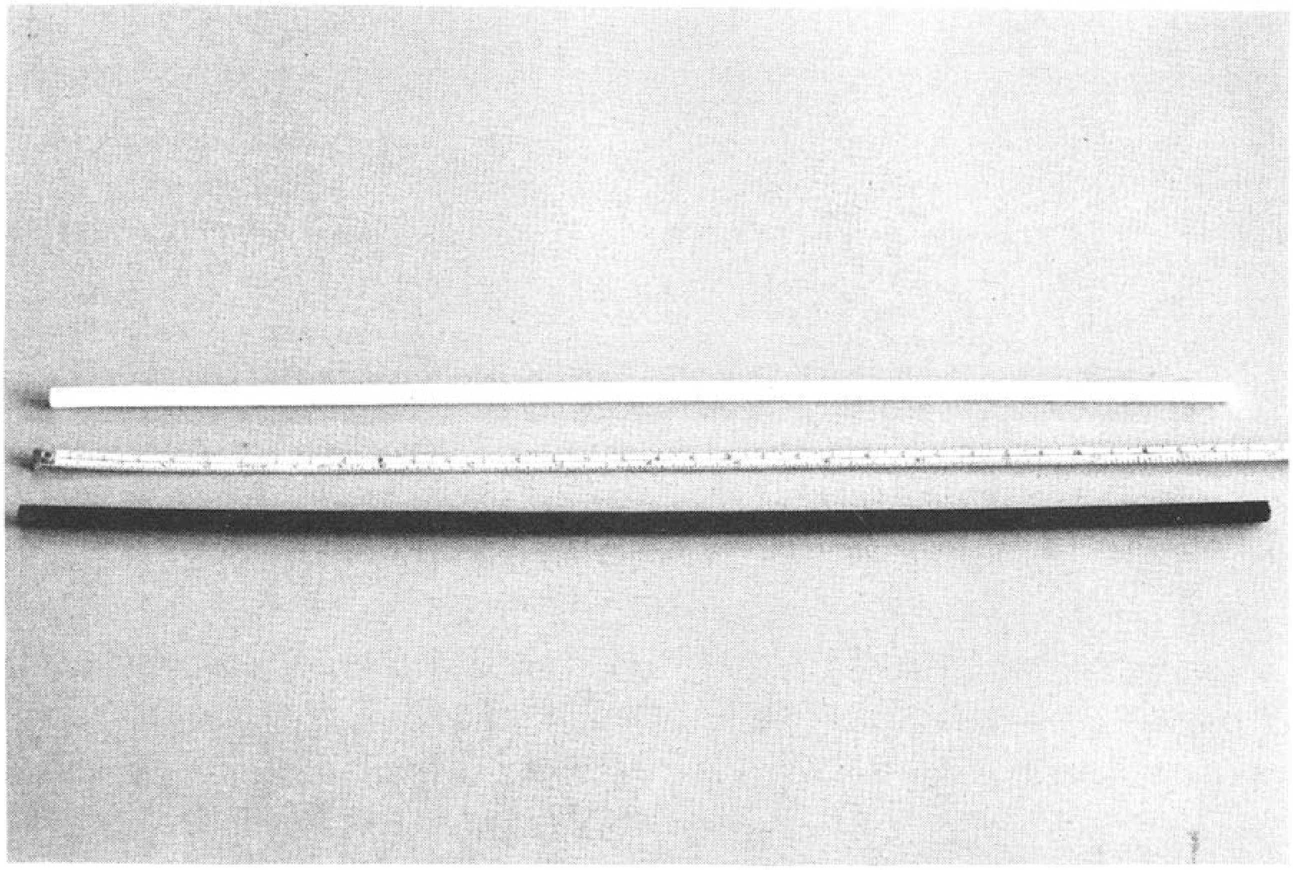


FIG. 12: Final Extruded Stick Propellant, LOVA Propellant (RDX/NQ/Kraton/Additive), Paste Propellant (NC/DEGN/Additive)

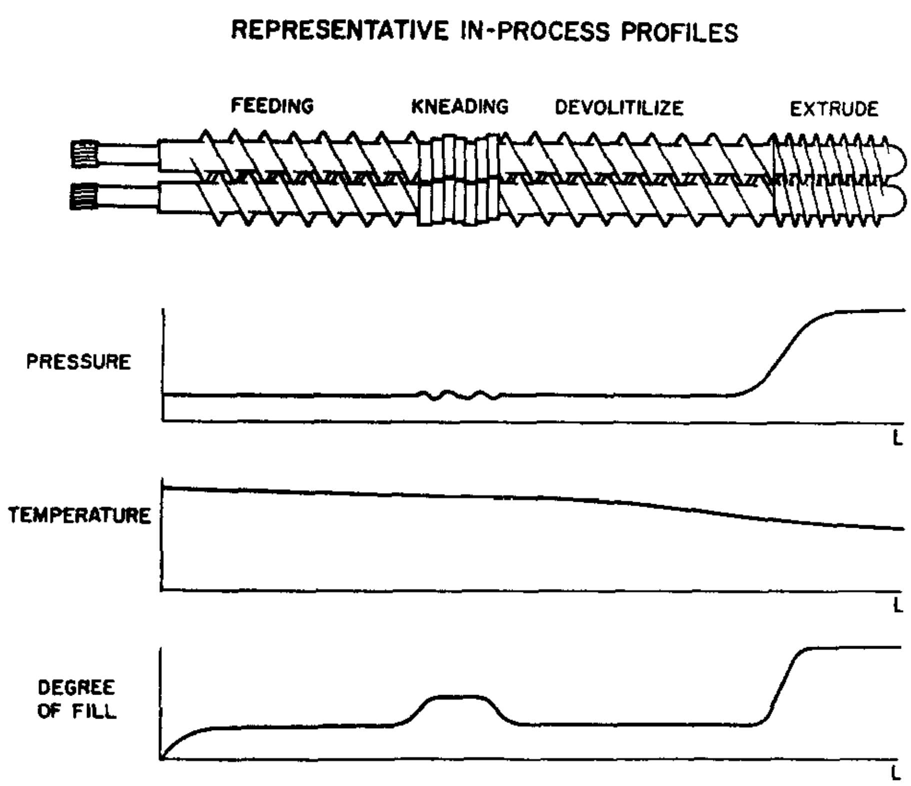
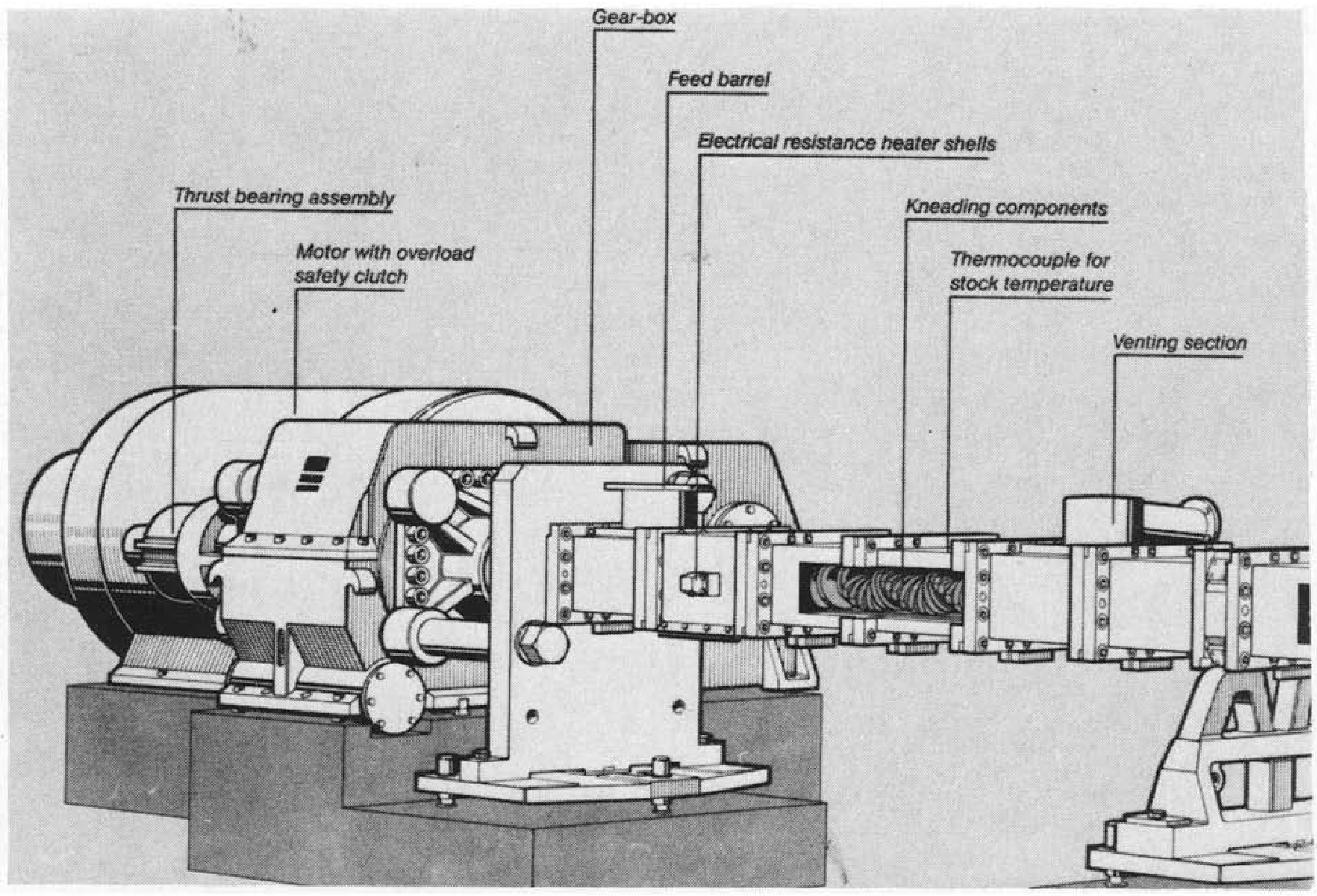



FIG. 13: The Representative Profiles of Pressure, Temperature, and Degree of Fill for Propellants




IG. 14: Cutaway of Production Extruder