GEAR PUMPS AND EXTRUDERS WITH GEAR PUMPS

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The following article considers the characteristics of gear pumps as they are increasingly gathering attention for precision extrusion and strainer applications in the extrusion of rubber.

1. Extrusion Principles of the（Single）Screw Rubber Extruder and Gear pump

The single screw rubber extruder is a constant pressure type pump that softens, pressurizes, and extrudes rubber compounds using frictional and shearing forces, between the rubber and barrel liner wall, with which the greater the extrusion pressure, the smaller the output becomes. The gear pump, on the other hand, is a constant output type extrusion pump, that outputs the rubber compound filling the space between the pump's revolving gear teeth by means of engaging the gear teeth, with which output remains constant even when extrusion pressure fluctuates（see Fig. 1）. With gear pumps, pulsation proportional to the number of teeth on the gear is generated in the rubber flow, because the rate at which volume is compressed by the engagement of the gear pump's teeth is not constant, even when the gear is revolving at constant speed. On the other hand, although the screw type rubber extruder does not have any factor causing such mechanical pulsation, fluctuation in the coefficient of friction（due to the influence of temperature, characteristics of rubber material, and operating conditions, etc.）between the rubber, the liner, and screw wall makes it conducive for extrusion output to fluctuate.

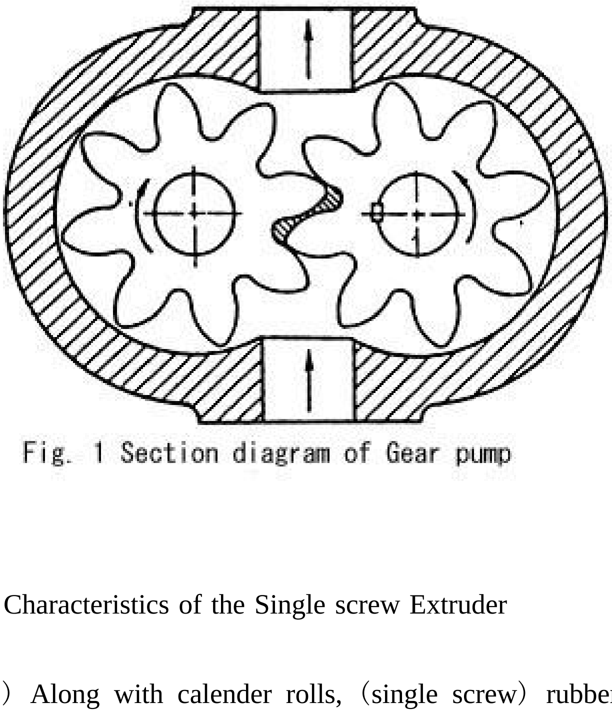

Fig. 1 Section diagram of Gear pump

2. Characteristics of the Single screw Extruder

（1）Along with calender rolls,（single screw）rubber extruders are the most extensively used equipment in the field of continuous rubber molding. Rubber extrusion exhibits the following characteristics as it is subject to thrust pressure caused by friction between the rubber compound and barrel wall, and shearing resistance pressure at the outlet die part.

（a）The greater the output pressure gets, the smaller the specific output（output/screw speed: kg/hr/rpm）becomes, and the higher the output rubber temperature rises as the amount of shearing induced heat goes up.

（b）As the screw's rotation becomes faster, shearing generated heat increases and output temperature rises. The output capacity of a rubber extruder is often limited by the output rubber temperature.

（c）When the viscosity level of rubber increases, the resistance pressure at the outlet die part increases, and specific output goes down.

（2）Air drawn into compounds extruded by rubber extruders

（a）Due to the degassing effect of its feed zone, the screw of a properly designed（single screw）rubber extruder attracts little air into its extruded rubber（see Fig. 2）

（b）When an extensive level of degassing is required, a screw that has a vent capability is built in.

（3）Self feed capability

Today's single screw rubber extruder comes with a feed roller unit, and thus possesses the ability to self-feed itself with rubber.

（4）Sealed part of high pressure rubber path structured without moving parts

The high-pressure pathway, through which rubber flows between the screw exit and output die, does not contain any moving part, and has a sealed structure with a simple design. In addition, no rubber leaks out of this sealed structure.

（5）Kneading effect

While the screw itself exerts some kneading effect, a screw with an even higher kneading capability designed into it can also be built in to the machine.

（6）Retention time

As the term "L/D ratio" for the screw's length indicates, the pressure raising capability and output are proportional to the length of the screw, for which reason the screw of a high-capacity extruder tends to be longer and retention time for such extruder tends to be lengthier as well.

（7）Self cleaning feature

Since an extruder screw possesses a self-cleaning feature, albeit a weak one, there is no need to remove the screw and clean it every time the type of material is changed.

（8）Rise time when commencing rotation

Because time is needed for the temperatures of the screw, barrel, and head to stabilize, it takes 3 to 10 minutes after screw rotation is commenced to start an operation.

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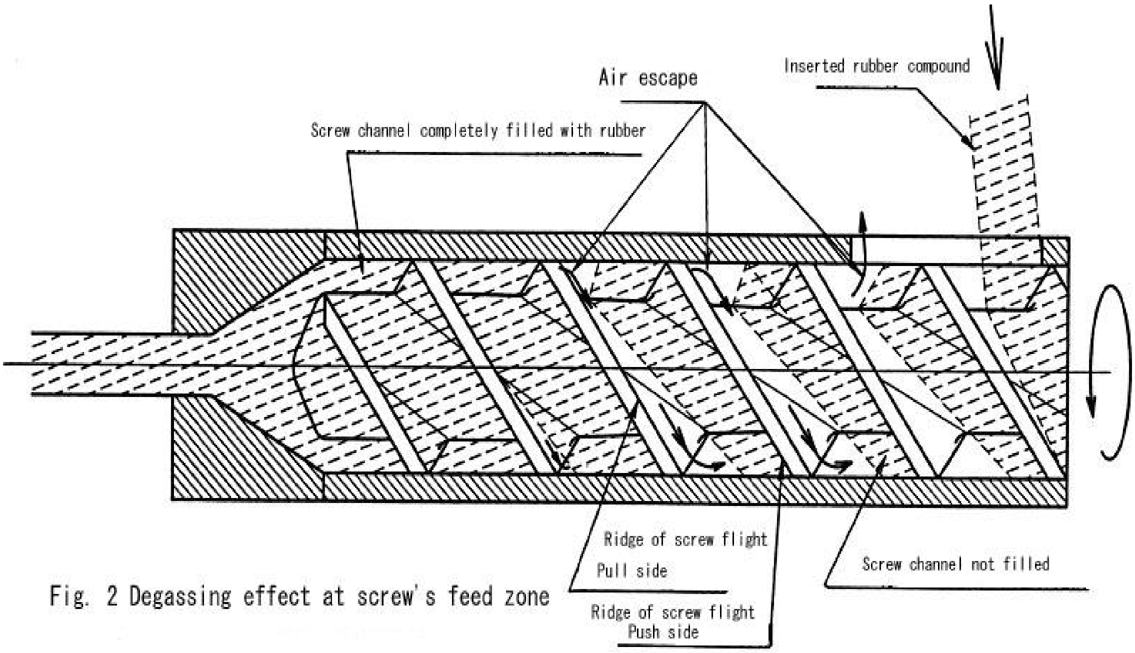


Fig. 2 Degassing effect at screw's feed zone

3. Features of the Gear pump

（1） Since its output quantity is constant, regardless of the relationship between the friction and shearing taking place between the rubber compound and barrel wall, the gear pump has the following characteristics.

（a） Specific output（output/screw rotation speed: kg/hr/rpm） will not change, and the increase in output rubber temperature, due to heat generated by shearing, is small, even when extrusion pressure is increased,.

（b） Since the amount of heat generated by shearing is small even when the gear revolution speed is increased, the size of the temperature increase（Delta T） is small, and specific output remains unchanged.

（c） Even when high viscosity rubber is extruded, an increase in extrusion pressure at the outlet die part will not change specific output quantity, nor will it increase output rubber temperature by any significant amount.

Thus, high outputs can be attained with gear pumps, even under high revolution speed and high extrusion pressure, since the extent of heat generated and temperature increase are small.

（2） Air drawn into compounds extruded by gear pumps

Since the feed zone of a gear pump is not capable of degassing, a lot of air gets drawn into its extruded rubber. Yet, introducing a degassing contrivance inside a gear pump would be difficult at the present time. Thus, the direct feed type gear pump mentioned later which does not incorporate an extruder（including those equipped with feed roller units）, is limited in use to upstream processes that precede the final extrusion molding process such as a straining process, or to applications that can tolerate a certain amount of air drawn in（or applications whose downstream process comes with a degassing scheme）.

（3）Since rubber compounds have high viscosity, it is difficult for gear pumps to self-feed themselves with such materials as in the case with water or oil. In order to extrude rubber compounds without drawing air into them, pressure must be applied to the entrance side of the gear pump（although the amount of pressure differs for different compounds, it is generally above 0.1MPa）.

（4）Self feeding ability

A gear pump whose gear teeth are given an undercut configuration at the inlet where the rubber is nipped into the gear pump, and has a set of two feed rollers built into it, possesses the ability to self-feed on rubber, but its self-feeding ability is inferior to that of a screw extruder.

（5）Sealed structure prevented by high pressure rubber path containing moving parts

Since the gear, which creates the extrusion pressure, is driven from the outside, a rotary seal that can withstand the high extrusion pressure becomes necessary between the drive and gear. With gear pumps for resin, a circulatory seal configuration, which returns rubber that got through the sealed part back to the gear pump inlet, is adopted as the structure of the rotary seal parts except for the drive shaft part, but in the case of rubber compounds, due to vulcanization, a phenomenon unique to rubber materials, the rubber gets scorched, making it difficult to adopt the circulatory seal structure except under special conditions.

Thus, rubber compounds that get through sealed parts are disposed outside the gear pump, and almost never recycled or reused. The quantity of rubber thus leaking from the rotary seal has been less than 0.1% of total output（during operations under 7 to 25 MPa） in actual cases.

（6）Retention phenomenon

A space that captures and confines materials forms when and where the gears get engaged, and rubber compounds captured into this space are returned to the inlet side（see shaded part of Fig.1）.

Since bearings and other parts can get damaged if abnormal pressure is generated when rubber compounds are completely sealed into this space, an escape channel is fabricated at the walls facing both sides of each gear teeth.

（7）Structure of gear bearings The bearing system that supports the gear pump consists of either journal bearings that use the rubber compound as lubricant, or rolling bearings. In the case of journal bearings, the bearing itself doubles as the rotary seal. Some gear pumps come with an additional cylindrical non-contact seal assembly with counter-flow groove, built in outside the journal bearings. As the gap between the journal bearings and gear shaft is extremely small, solids contained in the rubber compound such as hard impurities or fiber-reinforced rubber, etc., that is larger than this gap in the bearing part, can compromise bearing performance. Some pumps have specially designed grooves fabricated on the bore of the journal bearing to improve load capacity. Under a given rotation speed, journal bearings may cease to function and halt operation due to its characteristics, as the lubricant rubber membrane breaks and metal-to-metal contact occurs, and thus, ample caution is required. Rolling type bearings, on the other hand, have a cylindrical type non-contact seal assembly built in between the gear and bearings, with a counter-flow groove fabricated either on the bore or outer circumference of the cylinder. As rolling bearings use lubricants such as grease or lubrication oil, they do not face any operational limitation in the low-speed range like journal bearings. Due to their seals for lubrication purposes, etc., rolling bearing types are structurally more complicated than journal bearing types. Some pumps employ a cooling hole, for both journal and rolling bearing types, placed at the bearing center to remove heat generated at the gear and rotary seal, and come with a rotary joint to enable water cooling. The gear drive system has a universal join built in to prevent excessive external loads from applying to the bearing. Some pumps use slipper spline joints instead of the universal joint.

（8）Adoption of geared constant output mechanism to create extrusion pressure Although it is possible to achieve high precision outputs without being selective about rubber type, because of the constant output characteristic, the pulsation in the extrusion, whose frequency is proportional to the number of gear teeth（"number of gear teeth" x "rpm"/60:Hz）poses a limitation to extrusion accuracy. The pulsation may cause a continuous, irregular pattern called "gear mark" to be formed on the surface of the extruded product. To minimize pulsation, a helical gear with curved teeth, or a double helical gear with both left and right gears curved are used. While the curvature of the helical gear causes a thrust force to be generated against the sides of the gear teeth, the thrust force of double helical gears are canceled out and do not materialize. If the overall curvature angle of the teeth is too large, rubber will get blown from the outlet side toward the inlet side of the gear engagement, leading to reduced accuracy of extrusion and fluctuations in specific output. Some gear pumps adopt an assembly that utilizes the mechanism in which the following side of the double helical gear is also driven, and thus, no thrust force is generated. While precision of extrusion can be categorized into relative output precision（%）and absolute output precision（mass/time）, it is important to chose the criterion carefully. When output is great, even if the relative output precision（%）is good, there will be a drop in absolute output precision（g/sec）. This becomes a problem when conducting small output extrusions with a gear pump that has a large specific output quantity. Since the output of gear pumps, unlike that of extruders, is not influenced by the rubber compound's viscosity characteristics and coefficient of friction, it is not sensitive to the temperature control accuracy of the various components, but is directly influenced by the gear's rotational accuracy.

（9）Retention time and heat generated by shearing Since the length of a gear pump's pathway between its inlet and outlet, through which the rubber flows, is short, and the areas with shearing generated heat is limited to the gear engagement part, and the tips（addendum）and sides of the gear teeth, the amount of heat it generates is small compared to screw extruders that have large amounts of heat generated along the entire screw channel. Since the rubber's flow path is short, scorching of rubber does not occur easily either. A gear pump's specific energy, which is a measure of the amount of heat generated by shearing, is 0.01 to 0.03（kW/kg/hr） as compared to the rubber extruder's 0.06 to 0.21（kW/kg/hr）. Since the rise in temperature is small even under high-output and high-pressure extrusions, compared to extruders（whose mesh size is generally around #60）, the gear pump can be equipped with a very fine mesh size screen（#200 mesh size is possible）.

（10） Kneading effect Since a gear pump's rubber flow path is short, and it does not have a serious kneading zone, not much of a kneading effect can be expected from it.

（11） Self-cleaning characteristics and changing of material Because gear pumps retain rubber compounds at the root（deddendum） of its gear teeth, it does not have a self-cleaning capability, and the gear teeth often need to be exposed and cleaned every time the material is changed. A purging method, that purges the current residual material with the next material to be used, without exposing the gear teeth and cleaning them is available.

（12） Extrusion head An extrusion head with the same structure as that of a rubber extruder can be used, so there is no particular reason to reconfigure the structure to one that is geared specifically for a gear pump.

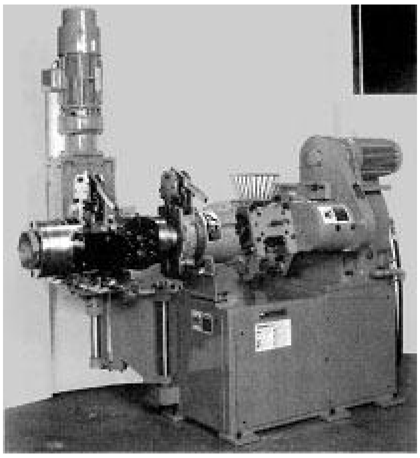
（13） Rise time when commencing operation Because of its constant output characteristic, the gear pump can start and stabilize in a short amount of time.

（14） Temperature control While gear pumps for plastics are temperature controlled solely by electric heaters, gear pumps for rubber are equipped with hot water jackets in their main body. Some pumps also come with a water-cool hole with rotary joint at the center of their gear shafts.

（15） Endurance Since ultra hard materials are used for critical parts such as gears and bearings, endurance is not considered to be an issue with gear pumps. Gear pumps are already widely used for resins, and judging from actual cases of gear pumps for rubber used abroad, it would be safe to conclude that they pose no problem in terms of endurance.

4. Characteristics of the Single screw Rubber Extruder with Gear pump While the single screw

Rubber extruder and gear pump have been compared with one another in the preceding sections, the single screw rubber extruder with gear pump, a merger of the two, is a highly superior extrusion device that compensates the shortcomings of gear pumps. An example of the single screw rubber extruder with gear pump is shown in Picture 1 and Figures 3-1 and 3-2.



Picture 1 Extruder with Gear pump for Rubber

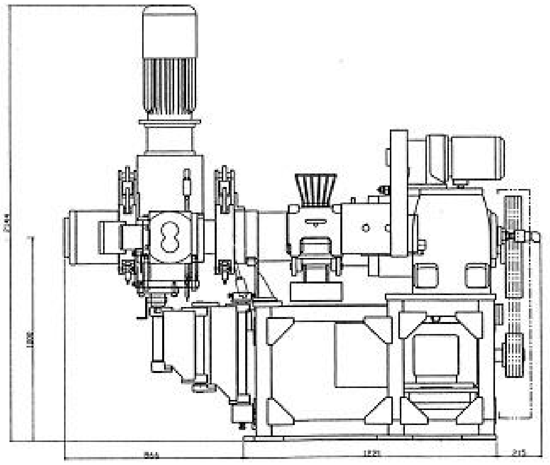


Fig. 3-1 Outline drawing（front view）

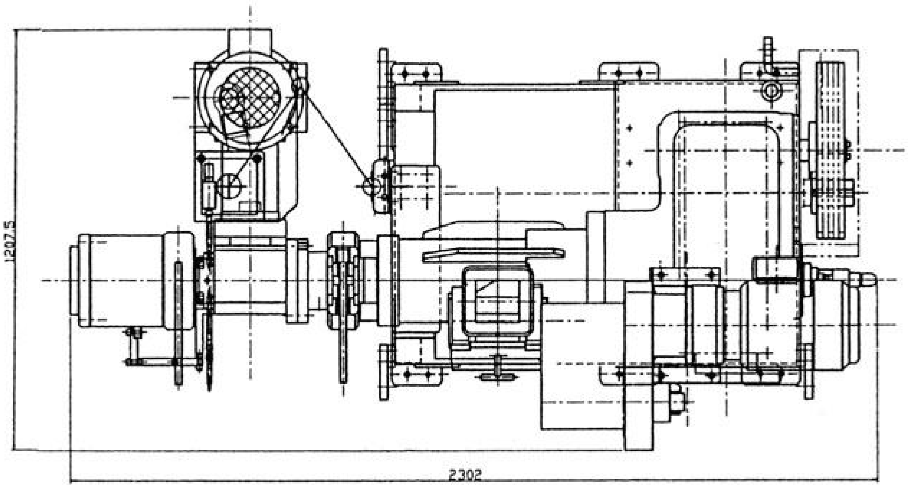


Fig. 3-2 Outline drawing（Plane view ）

（1）Suitability for general purpose use By feeding rubber compound from an extruder, the extruder is used as the material feeding device for the gear pump, and the material's pressure is increased by the gear pump whose output is constant. Due to this arrangement, specific output remains unchanged even under high output pressure or fluctuating rubber compound viscosity, and the amount of heat generated by the entire device is restrained and output rubber temperature does not rise, all while specific output does not change. Furthermore, since the screw extruder is only responsible for feeding the rubber compound to the gear pump, a small L/D ratio（3 to 6）will suffice.

（2）Degassing effect Since the rubber compound is fed from the extruder, and due to the degassing effect of the feed zone of the extruder, only a small amount of air is drawn into the rubber extruded by the entire device. If an especially powerful degassing feature is required, a screw with a large L/D ratio and vent capability can be built in.

（3）Rubber nipping performance and fluctuation of extrusion Since the rubber compound is fed by an extruder with feed roller, a self-feeding capability exists. Compared to the gear pump with feed roller, the rubber material is taken up by the gear pump in a much more stable manner, and breakage in the material feed flow is far less likely to occur. Since the constant output gear pump constitutes the compression zone of the device, it is not necessary to be selective about the rubber type, enabling high precision extrusion whether under high or low pressure（however, there remains some pulsation）. Table 1 shows output fluctuation from a best-case example.

Table 1 Fluctuation Test Data

Machine name	Single screw Rubber Extruder with Gear pump			
Screw	90 mm L/D5.2 (full flight type)			
Material	EPDM with Moony Viscosity Vm24～36			
Die size	ϕ5×10 L		ϕ10×10 L	
G/P rpm	10 rpm	20 rpm	10 rpm	20 rpm
No.	Extrusion weight [15g/second]			
	①	②	③	④
1	305.94	913.39	310.23	931.04
2	305.65	913.20	310.47	930.91
3	305.95	913.01	310.35	931.67
4	305.84	913.33	310.47	930.74
5	305.82	912.88	310.40	930.56
6	305.73	912.91	310.39	930.97
7	305.94	912.81	310.32	931.01
8	305.78	914.00	310.45	931.31
9	305.73	913.27	310.37	931.28
10	305.62	912.97	310.35	931.42
11	305.77	913.30	310.52	931.67
12	305.88	913.31	310.32	931.38
13	305.91	913.29	310.39	931.78
14	306.08	912.88	310.41	931.44
15	305.61	914.06	310.36	932.30
16	305.70	914.11	310.58	932.56
17	305.65	913.91	310.42	931.40
18	305.77	914.37	310.60	931.67
19	305.84	913.41	310.21	931.61
20	305.85	914.01	310.18	931.11
21	305.68	914.33	310.47	931.95
22	305.77	913.84	310.43	931.36
23	305.77	913.73	310.36	931.22
24	305.71	914.25	310.31	931.24
25	305.81	913.91	310.38	932.18
26	305.85	913.61	310.18	930.79
27	305.62	914.06	310.20	930.70
28	305.95	914.13	310.20	
29	305.76	913.82	310.27	
30	306.01	914.52	310.36	
31	305.78	914.02	310.22	
32	305.92	914.30	310.12	
33	305.91	914.28	310.34	
34	305.69			
35	305.73			
MIN[g]	305.61	912.81	310.12	930.56
MAX[g]	306.08	914.52	310.60	932.56
AVE [g]	305.80	913.67	310.35	931.38
R[g]	0.47	1.71	0.48	2.00
DEV [σ]	0.118	0.516	0.117	0.494
3σ/AVE×100 [%]	0.12	0.17	0.11	0.16
R/AVE/2×100[%]	0.08	0.09	0.08	0.11
OUTPUT [kg/h]	73.4	219.3	74.5	223.5

（4）Output rubber temperature When a comparison is made between equal outputs, the feed extruder has a smaller L/D ratio, smaller dimension（screw diameter）, and comparisons in specific energy（kW/kg/hr）produce the following result: Gear pump ＜ Extruder with Gear pump ＜ Screw Extruder. The output rubber temperature is lower for the same level of specific energy. A comparison of output rubber temperature between a single screw rubber extruder and rubber extruder with gear pump is shown in Fig. 4.

（5）The extruder plus gear pump combination can be arranged as a device for straining, for extruding general-purpose rubber products, or devised with a vent capability, or with kneading screw, etc. according to specific product needs.

（6）Screen mesh size A fine mesh size screen（example: #200 mesh）can be mounted between the gear pump and output die. To protect the gear pump, a coarse mesh size screen（#20, #30, etc., for example）can be installed between the extruder and gear pump.

（7）Installation space

Since the amount of space required for installation is about the same as that of a cold feed extruder with identical output capability, exchanges with existing extruders in currently operating lines is possible（see Figure 3）.

（8）Drive system and operation

Because two drive systems, one each for the extruder and gear pump, are required, it is often thought that operation will become more complicated. However, as with the case of gear pumps for resins, since the rotational speed of the extruder is automatically controlled by the controller so that the pressure at the gear pump inlet remains constant, by means of electric signals from a pressure sensor built in between the extruder and gear pump, only the gear pump's rotation needs to be operated. An inlet pressure controller is especially necessary when carrying out high precision extrusions.

（9）Rise time upon commencing operation

Because the constant-output gear pump is placed at the exit of the extruder, startup is fast and stable operation is reached quickly. As response to rotational speed is fast, gear pumps are used in precision variable cross-section extrusion molding as well. Data from when start-up was achieved in approximately 40 seconds by a 90mm rubber extruder with gear pump, with the gear pump operating at 5 rpm, is shown in Fig. 5.

(10) Setup change time (Rubber type change time)

Since the gear pump's gears can be cleaned, while the rubber compound is being ejected by the revolving screw inside the extruder, the operation setup can be altered in about the same amount of time as when only the gear pump was there. As with the stand alone gear pump, the rubber can be changed to the rubber compound for the next product, without disassembling and cleaning the gears, by means of the purge method.

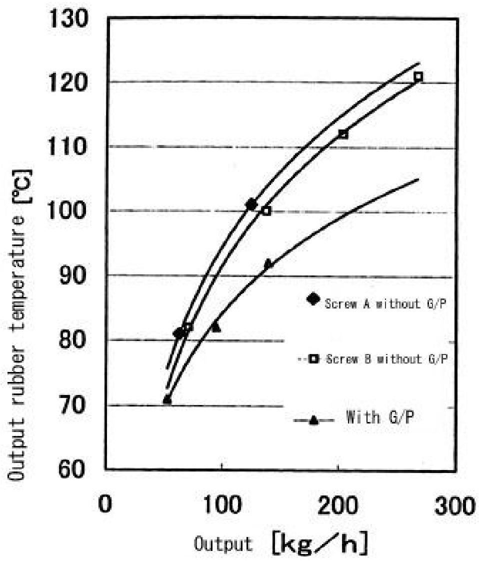
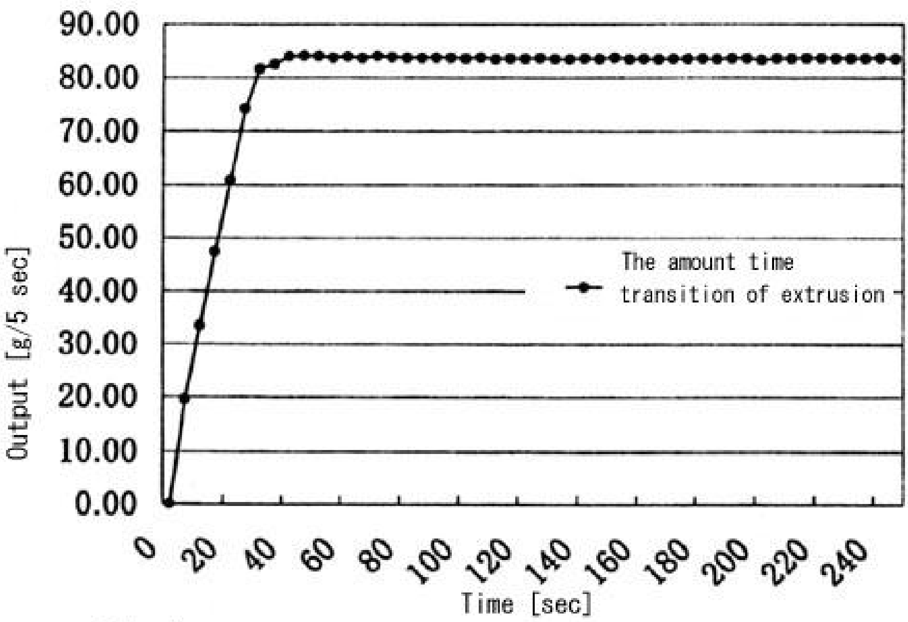


Fig. 4 Output-Temperature
With and without gear pump



90 mm Extrusion machine (L/D : 12) + ex70
G/P : 5 rpm Material : EPDM Machine : Pressure control Entrance : 50 kg/cm²

Fig. 5 Time till stable operation

Summary

The advantages and disadvantages of the single screw extruder, gear pump, and single screw extruder with gear pump, in continuous molding of rubber compounds were summarized. While the performance of gear pumps is superior in terms of their small output fluctuation, quick rise time, low heat generation during high-pressure extrusions, and quick response characteristic, because they draw too much air into rubber compounds, the single screw rubber extruder with gear pump, which adds a single screw extruder as the material feeder, is considered to be suitable to many production sites.

While gear pumps are beginning to be deployed in the domestic market to extrude rubber compounds in specialized applications such as tire production, we expect they will be adopted more widely in general purpose rubber extrusion fields.

A test machine is permanently installed at our Ueda Factory, which is available for extrusion tests by contacting our sales team.