Evaluation of the energy consumption of the recycling process of silane cross-linked polyethylene using supercritical alcohol.

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ABSTRACT

It is reported that silane-crosslinked polyethylene(Si-XLPE) which is used as insulation of cable can be recycled as thermoplastic polyethylene by supercritical methanol[1][2]. The critical point of methanol is 293°C, 7.99MPa. High pressure and high temperature is apt to waste large amount of energy.

Here, we represent the study on the energy consumption of the process developed for the recycling of Si-XLPE. It is revealed that the process using extruder is efficient for the supercritical fluid treatment of Si-XLPE in the aspect of energy consumption.

INTRODUCTION

There are the general discussions on the energy consumption of the recycling of plastics, which indicate that the recycling can be waste of energy in some cases[3]. Moreover, large amount of supercritical water or methanol require large amount of energy. So, the technology which can minimize the amount of supercritical fluid(SCF) to avoid wasting energy was required for the recycling process using SCF.

It was reported that the extruder can be used as a feeder and a reactor for the supercritical alcohol[4]. Supercritical fluid can be injected to the polymer because extruder can pressurize the polymer, which means that such process can minimize the amount of supercritical fluid and energy consumption.

In this report, we represent the study on energy consumption for the recycling of Si-XLPE by supercritical methanol. In the previous report, it is mentioned that silane cross-linked polyethylene (Si-XLPE) which is applied to insulation of cable can be recycled as thermoplastics by the chemical reaction in the supercritical methanol[1][2]. Extruder was applied to this chemical reaction as the continuous process for industrialization[3]. It is revealed that the required amount of methanol is 10phr (parts per hundred parts of resin) for the recycling of Si-XLPE. Obtained recycled PE satisfied the requirement of Japan industrial standard of insulation for 600V cross-linked polyethylene cable (600V XLPE cable)[5]. These results indicated that the recycled PE can be used as the same way as virgin PE. So, energy consumption to make recycled PE is compared with that of virgin PE in this paper.

MATERIALS AND METHODS

Materials

Si-XLPE pellet with 30% in the degree of gel fraction was gathered from the factory for the production of 600V XLPE cable. Methanol used here was made by WAKO Chemicals.

Equipment

The process was designed to make recycled PE from crushed Si-XLPE waste continuously and automatically. Scheme of the continuous process was shown in Fig.1. The twin screw extruders made by Japan Steel Works were used as equipment for chemical reaction (Ext-Chem) and degasing(Ext-Degas). Methanol was fed by high pressure pump from the methanol tank and heated to the supercritical state by the heater before it was injected to the Ext-Chem. The tubular reactor was attached to the Ext-Chem to keep Si-XLPE and methanol for more than 15min at 10MPa, 335°C. Pressure control valve was connected to the tubular reactor. Ext-Degas was mounted to the outlet of the pressure control valve to separate the recycled PE and the gas. Pelletizer was prepared to cut the recycled PE strand into the pellets. Whole electric power demand for this process was measured using the attached ammeter to evaluate the energy consumption.

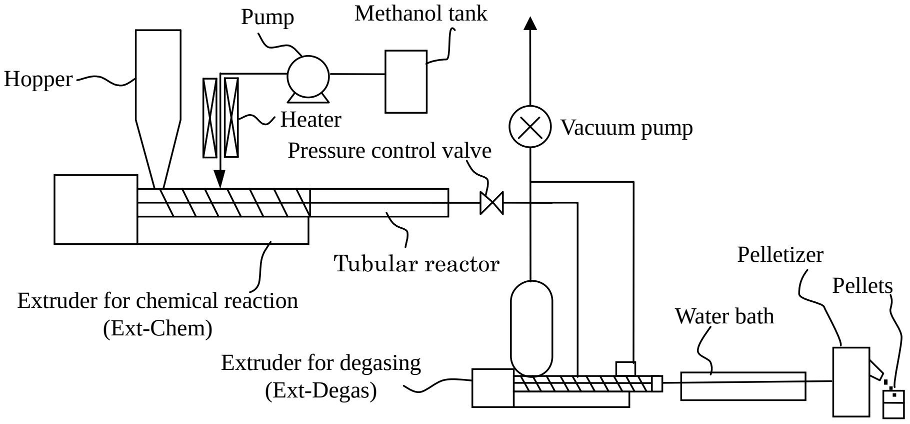

Fig.1 Schematic diagram of the continuous process for recycling of silane-XLPE by supercritical alcohol using twin screw extruders.

Method

40kg/hour of Si-XLPE was charged to the extruder from the hopper, then 10phr of alcohol was injected to the Ext-Chem. Injected supercritical alcohol was kept over 300°C at 10MPa. The reactor was kept at 330°C and 10 MPa. The Ext-Degas was set at 200°C to extrude the recycled PE.

RESULTS

Electric power demand for this process is shown in Fig.2. Power demand is stable at around 160A 200V, which means that the process was well controlled in 10 hours. The average electric power demand in 10hours is 159.3A, 200V.

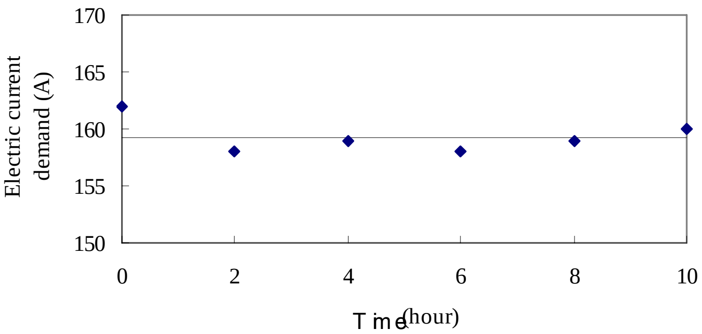

Fig.2 Electric power demand for the recycling.

LIFE CYCLE ENERGY ASSESSMENT

600V XLPE cable is the target application of this technology. The structure of 600V XLPE cable is shown in Fig.3. Conductor is covered by insulation and sheath.

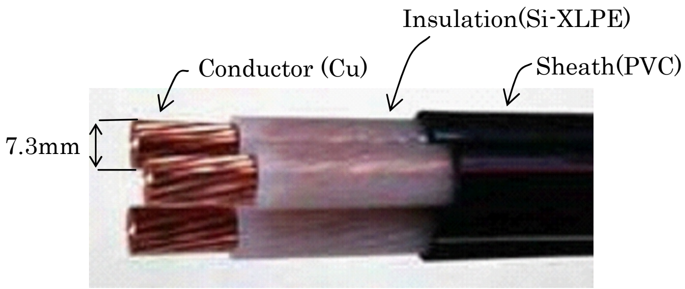

Fig.3 Structure of 600V XLPE cable.

Fig.4 and Fig.5 represent the process for production of 600V XLPE cable using virgin PE and recycled PE as insulation respectively. The same copper(Cu) and polyvinyl chloride(PVC) can be applied to the virgin and the recycled product as the conductor and sheath respectively. It is reported that recycled PE can be used as same as the virgin PE[5], which means that energy used for the cable processing should be the same in each product. So, the system boundary was determined as hatched box in Fig.4 and Fig.5. Energy consumption to produce the recycled PE was compared with that of the virgin PE in this study. Life cycle energy assessment of the hole process for the production of cable is reported in another paper[6].

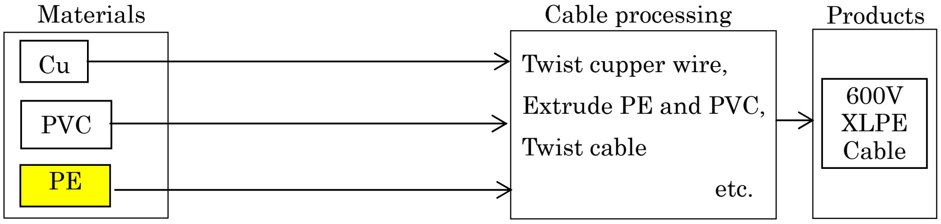

Fig. 4 Process for the virgin products.

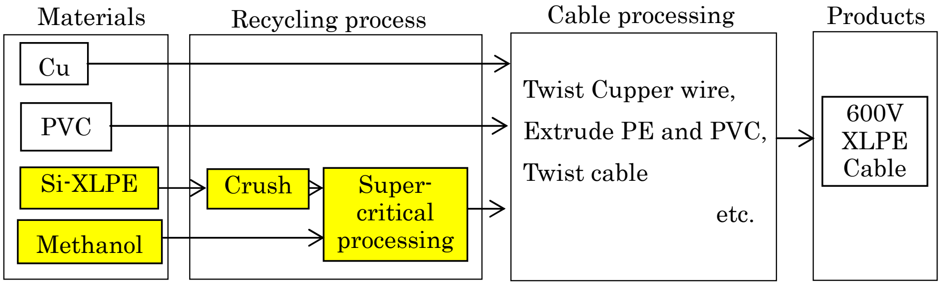

Fig.5 Process for the recycling products.

We assume that the Si-XLPE was gathered from the cable factory and recycled on that site. Energy unit bases of virgin PE, methanol, electric power and steal were represented in Table 1 [7][8]. These values were converted to the energy per 1kg of PE for calculation.

Table 1 Energy unit base.

	Parameters	Unit base
PE	U_{PE}	7054 kcal/kg
Methanol	U_{MeOH}	5431 kcal/kg
Electric power	U_{ele}	2250 kcal/kWh
Steel	U_{Fe}	6125 kcal/kg

Energy for the recycled PE (E_r)was represented as following equation.

$$E_r = U_{MeOH} + E_1 + E_2 \qquad \cdots \ (1)$$

E_1 and E_2 are the energy consumption for crushing Si-XLPE and for the supercritical processing respectively for the 1kg of PE. Energy consumption for each unit process is represented as follows.

$$E_n = E_n^{'} + E_n^{''} \qquad \cdots \ (2)$$

$E_n^{'}$ is electric energy consumption per 1kg of PE, which was estimated equal to the volt-ampere(VA) per 1kg of PE. Measured electric demand shown in Fig.2 was used for evaluation of that of the supercritical processing. On the other hand, electric demand for the crusher was estimated as 30% of the electric capacity of crusher which can treat 40kg/hour of the Si-XLPE waste.

$E_n^{''}$ is energy requirement to make the equipment in the unit process per 1kg of PE. $E_n^{''}$ is represented as following equation.

$$E_n^{''} = \frac{E_n^{'''}}{V_n \times D_n \times Y_n \times R_n} \quad \cdots (3)$$

$E_n^{'''}$: Energy requirement to make the equipment (kcal)

V_n : Productivity of PE (kg/hour)

D_n : Operation time in the year (hour/year)

Y_n : Life span of the equipment (year)

R_n : Occupation rate of equipment for the product(-)

Equation (4) was used to estimate $E_n^{'''}$.

$$E_n^{'''} = \sum_l U_l W_l \quad \cdots (4)$$

W_l is weight of the part of equipment(kg). U_l(kcal/kg) is unit base of the materials of which part of equipment consist. Equipment used as crusher and for the supercritical treatment mainly consist of steel. So, we calculate the energy consumption for the production of the equipment as following equation instead of equation (4).

$$E_n^{'''} = U_{Fe} W_n \quad \cdots (5)$$

W_n is total weight of the equipment for the unit process(kg). U_{Fe} is unit base of steal (kcal/kg). The found energy consumption is shown in Table 2. The required energy for the recycling of Si-XLPE was smaller than that of virgin PE. These results indicate that the recycling of Si-XLPE using supercritical alcohol can save the energy consumption.

Moreover, further information about the recycling process is revealed as follows. Energy required for the construction of the equipment is smaller than that of the electric energy used for the operation of the equipment. Electric energy was mainly used as the energy source for the heaters and for the motors. So, these results indicate that the heat insulation and the efficiency of the motors are important matter to save energy rather than the size reduction of the equipment.

Table 2 Energy analysis of the recycled PE.

		Recycled PE (kcal/kg)	Virgin PE (kcal/kg)
E_{MeOH}		244.4	-
E_{PE}		-	7054.0
E1	$E_1^{'}$	0.6	-
	$E_1^{''}$	103.7	-
E2	$E_2^{'}$	17.0	-
	$E_2^{''}$	2240.2	-
Total		2605.9	7054.0

CONCLUSION

The energy consumption for the recycling of Si-XLPE is studied. It is indicated that energy can be saved if the extruder is applied as a feeder and a reactor for the reaction in the supercritical methanol. Life cycle energy assessment can give an answer to the criticism which point out the wasting of energy because of the high pressure and temperature of supercritical methanol. Moreover, the results give us the principle of the development for more efficient process.

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