To Study the Effect of Temperature and Velocity Parameters on Coating Performance of Wire Coating Process

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ABSTRACT

Progress in analysis of Wire Coating Process is reviewed. Due to high speed, too low a temperature, too high temperature etc. limitations are a result of the failure to get uniform thickness of coating on the wire during operation. Recent advances need more experimental data and also include the numerically nonisothermal flow of analysis method. This analysis can be used for optimum operating conditions and for better performance. So a general purpose analytical method used to allow the process for faster wire speed without occurrence of rough coating surface.

Keyword: - *wire coating, extrusion, temperature, coating thickness, velocity of the wire, pvc coating*

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1. INTRODUCTION

The wire-coating process is a continuous extrusion process for primary insulation of conducting wires with molten polymers for mechanical strength and environmental protection purposes. The molten plastic is extruded into a crosshead through which passes the wire to be coated in a continuous manner. The process operates at maximum possible pressures, temperatures, and speeds. Wire-coating lines are very expensive in terms of capital investment in machinery.[3]

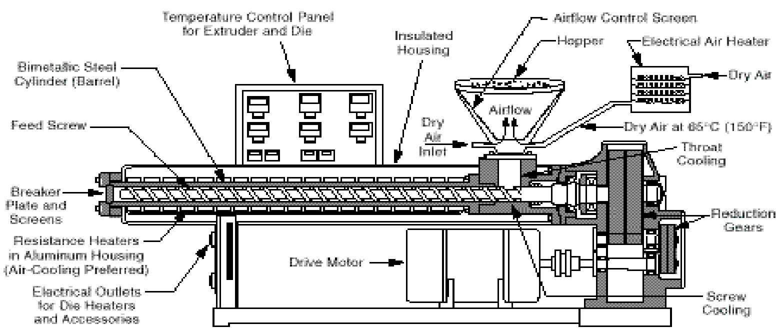

Fig-1 Typical Wire Coating Technique [17]

The process is a high-quality operation, and this is reflected in costs and quality of equipment. Typical wire-coating technique consist of an assortment of equipment as shown in Figure 1.

1.1 Wire Coating Dies

There are two basic types of wire coating dies that can be fitted to the crosshead which illustrated in Fig 2(a) Pressure Die and 2(b) Tubing Die. In tubing dies the importance lies mainly outside the die where the melt meets the wire. However, little effort has been spent so far in studying the polymer flow outside tubing dies. In pressure dies, where the melt meets the wire inside the die, a complex flow field exists, and its understanding is necessary for the design of better dies with optimum performance. It is, therefore, the pressure dies that have attracted most attention in the wire-coating process, and they will also be the focus of this review.[3]

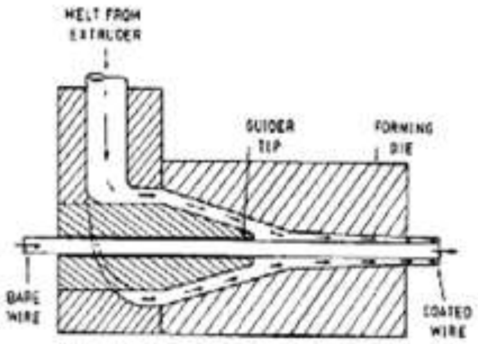

Fig-2(a) Pressure Die

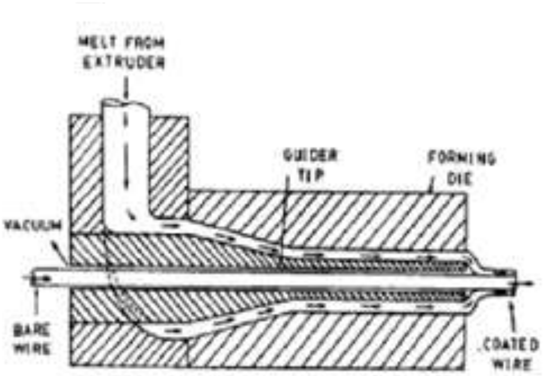

Fig-2(b) Tubing Die

2. LITERATURE REVIEW

S. Akter and M.S.J Hashmi [1] analyze the some limitation in the wire coating experimental set up the wire speed limited to 13 m/sec, Therefore experiments carried out within the speed range of 1 and 12.5 m/sec. the polymer coating on wire is continuous and of uniform thickness for speed of up to 12 m/sec. also the bonding quality of the coating with the wire was very good and the back pressure on polymer introduced by argon and melt temperature do not affect the coating quality.

R.E. Lamb and M.S.J. Hashmi [2] from the practical performance, the wire is exceeded at speeds greater than 20 cm/s, hence the discontinuous coating of the wire. A similar set of experiments were carried out with the same polymer at 200 ° C but no conclusive results about the coating thickness variation with speed were obtained. With the results they concluded that it seems possible to coat fine wire of diameter of the order of 0.15 mm diameter at low drawing speeds.

Roy Wagner and Evan Mitsoulis [3] concluded that the wire coating process has been numerically simulated by using Finite Element Method and LDPE operating at temperature around 260 c° and wire speed up to 3000 cm/sec and also concluded that the temperature effects in wire coating are very important and indispensable in obtaining realistic values, especially in area of stress singularities such as the impact point and die exit.

Evan Mitsoulis [4] using most Mathematical models wire coating are based on the Lubrication approximation in one direction under isothermal condition and concluded that the analysis is usually performed in the die section with or without taper and due to the sever conditions experienced by the melt in high speed wire coating operations, it has been postulated that slip at the wall may be occurring and that viscoelastic effects may also be quite important.

Muhammad Asif Javed, Nasir Ali and Tasawar Hayat [5] from the Experimentation they concluded that a wire-coating problem is studied using melted polymer satisfying the PTT viscoelastic model. An analytical solution is presented for the complete PTT model with a linear form of the stress coefficient and for a simplified PTT model with an exponential version of the stress coefficient.

Sang-Yeoun Yoo & Yogesh Jaluria [6] from the practical performance they concluded that the meniscus generated at the optical fiber die exit was simulated numerically. The fiber speed and the die exit diameter were found to be key parameters during the optical fiber coating process. When the fiber speed increases, the surface tension effect near the die exit becomes negligible due to the much higher inertia and viscous forces.

S. Akter, M.S.J. Hashmi [7] they were carried out within the speed range of up to 12 m/s. The polymer coating on the wire is continuous for speeds of up to 12 m/s. The bonding quality of the coating with wire was found to be very good. Concentricity is better in the case of pressure unit with h2 equal to 0.05 and 0.12mm but poor for the pressure unit with h2 equal to 0.03 mm. Application of back pressure generally improves the quality of the coating.

S.Akter, M.S.J.Hashmi [8] they concluded that within the speed range between 2 and 12 m/s, the polymer coating on the wire is continuous and concentric for speeds of up to 12 m/s. The bonding quality of the coating with wire was very good. The coating thickness and drawing force in general is higher for higher backpressure.

A.Baloch,H.Matallah,V.Ngamaramvaranggul and M. F. Webster [9] in the case of short-die pressure-tooling flow, there was no melt-wire sudden contact and smooth solutions were established on the wire at the die-exit and In contrast, focusing on tube-tooling design, stress and pressure build-up is realized in the land-region section, as with pressure-tooling.

Michael T. Hillery, Vincent J. McCabe [10] said that wax/colloidal graphite lubricant proved to be the most efficient at all temperatures for this research. However in the temperature range 300-400°C polyethylene proved to be an excellent lubricant on 'unpicked' wire, which has major environmental implications. Tungsten carbide proved to be the most satisfactory die material at all temperatures.

J G Khan, R S Dalu and S S Gadekar [11] analysis of the various papers on the defect and observing their views of researchers by paper in extrusion process there should be need of minimizing its causes for the best extrusion product. These quality problems (Causes) are become inappropriate setting of operational parameters as per observation. By the application of above remedies the percentage of loss would be improve, as predicted, for the products.

Milivoje M. Kostic, Louis G. Reifschneider [12] optimize the die design to make the necessary adjustments practically possible. This is why polymer extrusion die design has most often relied on experience, empirical data, and expensive trial and error adjustments to design and optimize a die and complementary process parameters.

Changsun Moon, Naksoo Kim [13] procedures of inverse engineering to determine the friction and thermal conditions in the wire-drawing process are proposed by measuring the drawing force and\ the transition curve of temperature at a certain position of the die assembly. The analysis tool used in inverse engineering was a commercial finite element analysis program based on elastic-plastic deformation and coupled heat transfer algorithm.

E.M. Rubio, A.M. Camacho, L. Sevilla, and M.A. Sebastian [14] given the idea about FEM which is a method more accurate than SM because the obtained results with it are nearer to the real results.SM forward tension curves only are similar to experimental and FEM ones for low reductions carried out in dies with low semi angles and under low friction conditions.

3. EXPERIMENTAL PROCEDUER

The experimental set up consists of the drawing bench, the electrical installations, the wire feed mechanism, the drive system, the polymer feeding and melting unit and the pressure unit. A schematic diagram of the process is shown in Fig. 1. The polymer granules are poured in the hopper which is fitted with a heater band. The hopper is connected to the melt chamber and a gas bottle of pressurized argon is connected through a pressure line to the hopper which provides the back pressure in the polymer melt. The argon protects the polymer melt from thermal degradation and it also works against the irregularities of coated surface. During the coating process at first the wire enters the leakage control unit (which also acts as a wire preheating unit) attached to the melt chamber. The wire passes through the melt chamber and enters the pressure unit where coating forms on it due to the hydrodynamic pressure. The coated wire is then wound on the bull block which is driven by a continuously variable speed motor.[17]

3.1 Mechanism of Flow

As the plastic moves along the screw, it melts by the following mechanism. Initially a thin film of molten material is formed at the barrel walls. As the screw rotates it scrapes this film off and molten plastic moves down the front face of the screw flight. When it reaches the core of the screw it sweeps up again, setting up a rotary movement in front of the leading edge of the screw flight. Initially the screw flight contains solid granules but these tend to be swept into the molten pool by the rotary movement. As the screw rotates, the material passes further along the barrel and more and more solid material is swept into the molten pool until eventually only melted material exists between the screw flights.As the screw rotates inside the barrel, the movement of the plastic along the screw is dependent on whether or not it adheres to the screw and barrel. In theory there are two extremes. In one case the material sticks to the screw only and therefore the screw and material rotate as a solid cylinder inside the barrel. This would result in zero output and is clearly undesirable. In the second case the material slips on the screw and has a high resistance to rotation inside the barrel. This results in a purely axial movement of the melt and is the ideal situation. In practice the behavior is somewhere between these limits as the material adheres to both the screw and the barrel. [18]

The useful output from the extruder is the result of a drag flow due to the interaction of the rotating screw and stationary barrel. This is equivalent to the flow of a viscous liquid between two parallel plates when one plate is stationary and the other is moving. Superimposed on this is a flow due to the pressure gradient which is built up along the screw. Since the high pressure is at the end of the extruder the pressure flow will reduce the output. In addition, the clearance between the screw flights and the barrel allows material to leak back along the screw and effectively reduces the output. This leakage will be worse when the screw becomes worn.The external heating and cooling on the extruder also plays an important part in the melting process. In high output extruders the material passes along the barrel so quickly that sufficient heat for melting is generated by the shearing action and the barrel heaters are not required. In these circumstances it is the barrel cooling which is critical if excess heat is generated in the melt. In some cases the screw may also be cooled. This is not intended to influence the melt temperature but rather to reduce the frictional effect between the plastic and the screw. In all extruders, barrel cooling is essential at the feed pocket to ensure an unrestricted supply of feedstock. [18]

3.2 Flow Models

The concepts of Newtonian and non-Newtonian fluids can be well acknowledged when viscosity is explained. The viscosities of some fluids depend on shear rates whilst others are not. It may be recalled that the viscosity of fluid is result of internal friction of fluid molecules.

Newtonian Fluids: Fluids with constant viscosity at constant temperature independent of shear rate are Newtonian fluids; example is water. The figure below shows how fluids are characterized as Newtonian and non-Newtonian in relation with shear. Google [19]

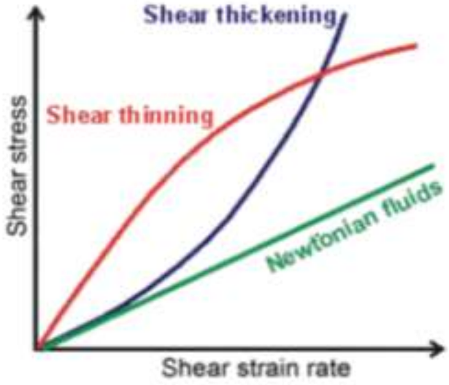

Fig-3 Newtonian Fluids

Non-Newtonian Fluids: The viscosity of polymer melt (complex fluids) at a constant temperature depends on shear rate. The structures of the fluid change with shear rate. A fluid that has its viscosity depending on a shear rate at constant temperature is called a non-Newtonian fluid (Chung, 2000). There are two types of non-Newtonian fluids. These are dilatants and pseduoplastics. “The viscosity of the dilatants fluid increase with shear” and “the viscosity of the pseduoplastics fluid decrease with shear” (Chung, 2000, p.102). The pseduoplastics are shear thinning fluids whilst the dilatants are the shear thickening fluids. [20]

4. NUMERICAL DISCUSSIONS

4.1 Flow Analysis

The pressure distribution of the flow in the extruder is the total output obtained from the drag flow, back pressure flow and leakage. Assuming that there is no leakage.

$$Q = \frac{1}{2}\pi^2 D^2 \mathrm{NH}\ \sin\emptyset\, cos\emptyset - \frac{\pi D H^3 sin^2\emptyset}{12\eta}\,\frac{\mathrm{P}}{\mathrm{L}} = Q_d - Q_p$$

Where,

Qd – Drag flow (m3/s)
Qp – Pressure flow
D – Diameter of the screw (m)
N – Screw revolution (rpm)
H – Channel depth of the screw (m)
Ø – Helix angle of screw
L – Length of the screw (m)
P – Operation pressure (Pa)
η–Viscosity (Pa.s) $= m\,\gamma^{n-1}$

When there is no pressure build up at the end of the extruder, any flow is due to drag and maximum flow rate Qmax can be obtained. The equation then can be reduced to only the drag term as follows.

$$Q = Q_{max} = \frac{1}{2}\pi^2 D^2 \mathrm{NH}\ \sin\emptyset\, cos\emptyset$$

Similarly, when there is a high pressure drop at the end of the extruder the output of the extruder, Q becomes equal to zero (Q=0) and the maximum pressure is obtained from the equation. [18]

$$\frac{1}{2}\pi^2 D^2 \mathrm{NH}\ \sin\emptyset\, cos\emptyset = \frac{\pi D H^3 sin^2\emptyset}{12\eta}\frac{P}{L}$$

$$\text{Hence } \mathrm{P} = \mathrm{P}_{\max} = \frac{6\pi DLN\eta}{H^2 tan\emptyset}$$

4.2 VELOCITY OF THE WIRE: It is necessary that a wire must increase in speed for the same volumetric rate of material to enter and exit the die. Volumetric rate is defined as the cross-sectional area of the wire multiplied by the wire velocity. This can be expressed mathematically as,[22]

$$V_i\frac{3.14159xd_i^2}{4} - V_f\frac{3.14159xd_f^2}{4}$$

where *Vi* and *Vf* represent the wire velocities (feet or meters per minute) and *di* and *df* are the wire diameters (inches or millimeters) entering and exiting the die, respectively. For circular wire, Equation can be simplified and reduced to:

$$V_i\, d_i^2 = V_f\, d_f^2$$

4.3 TEMPERATURE: Heat is generated primarily by work of deformation (reduction) and sliding (friction) at the die surface. Adiabatic heating is proportional to the amount of deformation; therefore, heating and temperatures are higher at the wire surface than at the centerline. Although the temperature rise (Δ*T)* in the wire can be obtained by using an empirical equation proposed by Wilson [22]:

$$\Delta T = \frac{1.069\ x\ 10^4\ x\ F}{C\ x\ A_f\ x\ \rho}$$

Where, *F* is the die pull, C is specific heat capacity of steel die (cal per gm per ºC = 0.1153 at 100ºC), *Af* is final wire cross-sectional area, and ρ is density of steel die.

4.4 SHEAR RATE

The difference in velocity per unit normal distance. The rate of shearing or shear rate is one of the most important parameters in polymer melt processing. If the process is to be described qualitatively, the shear rate in the fluid at any location needs to be known.[21] Shear rate,

$$\gamma = \frac{6\ Q}{W\ H^2}$$

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1 Process Parameters

Polymer Characteristics:

Polymer Type: Polyvinyl Chloride

Polymer Melt Temperature: 180 - 210°c

Wire Characteristics for Pressure Die:

Wire Diameter: 4.5 mm

Wire Material: Aluminum

Wire Characteristics for Tubing Die:

Wire Diameter: 14.5 mm Wire Material: Copper

Input Parameters:

1. Die, 4 Barrels and Head Temperatures (°c)
2. Screw Speed (rpm)
3. Pressure (5-10 bar)
4. Wire Speed (m/sec)

Output Parameter:

1. Coating Thickness (mm)

5.2 Experimental Result

Experimental Name : Wire Coating Process (by using Pressure Die)
Measuring Parameters : Die Temperature and Coating Thickness
Wire Diameter : 4.5 mm
Wire Material : Aluminum
Coating Material : PVC
Time Interval : 5 min

SR. No	Screw Speed (rpm)	Head Temperature Heating C°	Barrel : 1 Heating C°	Barrel : 2 Heating C°	Barrel : 3 Heating C°	Barrel : 4 Heating C°	Die Heating C°	Wire Speed (m/s)	Coating Thickness (t in mm)
Setting Value	630	162	164	166	167	168	150	2660	0.75
1	630	162	163	165	167	167	150	2660	0.7475
2	629	163	163	165	167	168	150	2661	0.7475
3	629	161	164	166	166	168	151	2659	0.7475
4	628	162	164	165	167	167	150	2660	0.7480
5	629	162	165	166	168	169	150	2660	0.7480
6	630	162	164	166	166	168	150	2661	0.7485
7	630	162	165	165	167	168	150	2660	0.7485
8	630	163	164	165	167	167	149	2658	0.7485
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16	631	162	164	167	168	168	151	2661	0.75
17	630	163	164	167	168	167	150	2659	0.75
18	630	162	164	165	167	168	151	2658	0.75

19	629	163	164	166	166	168	149	2659	0.75
20	630	162	163	166	165	169	148	2660	0.75
21	631	162	164	166	166	168	149	2661	0.75
22	630	161	165	165	165	168	150	2661	0.75
23	630	162	164	167	168	167	150	2660	0.75
24	630	162	164	166	167	168	150	2660	0.75
25	630	162	164	166	167	168	150	2660	0.75

Experimental Name : Wire Coating Process (Tubing Process by using Tubing Die)
Measuring Parameters : Die Temperature and Coating Thickness
Wire Diameter : 14.5 mm
Wire Material : Copper
Coating Material : PVC
Time Interval : 5 min

SR.	Screw Speed	Head Temperature	Barrel : 1	Barrel : 2	Barrel : 3	Barrel : 4	Die	Wire Speed	Coating Thickness
No	(rpm)	Heating C°	Heating C°	Heating C°	Heating C°	Heating C°	Heating C°	(m/s)	(t in mm)
Setting Value	310	161	165	168	170	175	140	1290	1.25
1	310	160	165	168	170	173	138	1285	1.2490
2	309	160	165	167	169	173	139	1286	1.2490
3	309	162	164	167	169	174	139	1287	1.2490
4	308	161	166	168	171	175	140	1287	1.2490
5	309	161	165	168	170	175	140	1289	1.2490
6	310	161	164	169	171	176	140	1290	1.2495
7	310	161	165	168	170	175	140	1290	1.2495
8	310	161	165	168	170	175	141	1290	1.2495
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17	311	161	165	168	170	175	138	1291	1.25
18	311	160	166	167	170	174	139	1291	1.25
19	310	161	165	168	170	175	140	1290	1.25
20	309	161	164	168	171	175	140	1290	1.25
21	310	161	165	167	170	175	141	1289	1.25
22	310	161	165	168	170	175	140	1290	1.25
23	310	161	165	168	170	175	140	1290	1.25
24	310	161	165	168	170	175	140	1290	1.25
25	310	161	165	168	170	175	140	1290	1.25

6. CONCLUSION

From the Experimental survey, at the 12.9 m/sec total thickness of the coated wire is 2.5 mm and at 26.6 m/sec wire speed we got 1.5 mm total thickness of the coated wire. So we conclude that the Smoothness of the coating on the wire can improve by maintain the temperature of die and barrels and wire speed of the wire coating process, we also concluded that the Coating thickness of the wire is inversional proportional to the wire speed. An inclusion of effects of various process parameters in setup used in the numerical and simulation analysis are of primary importance of the Future work.

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