MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
Misr J. Ag. Eng., 39 (1): 153 – 172

ISSN-Print: 1687-384X
ISSN-Online: 2636-3062
DOI: 10.21608/mjae.2021.89632.1040

MODELLING OF HEAT AND MASS BALANCE OF PRECONDITIONING AND EXTRUSION STAGES FOR FLOATING FEED PRODUCTION

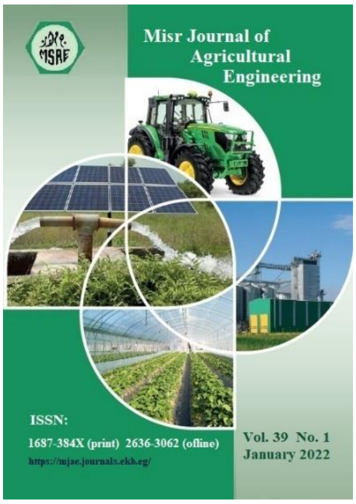
I. F. El-Adly[1], A. H. Bahnasawy[2], S. A. Ali[2] and E. G. Khater[3&*]

[1] Assist. Lect., Ag. Eng. Dept., Fac. of Ag., Benha U., Egypt.

[2] Prof. of Ag. Eng., Ag. Eng. Dept., Fac. of Ag., Benha U., Egypt.

[3] Assoc. Prof. of Ag. Eng., Ag. Eng. Dept., Fac. of Ag., Benha U., Egypt.

E-mail: alsayed.khater@fagr.bu.edu.eg



Keywords:
Heat balance; Mass balance; Mathematical model; Preconditioning; Extrusion; Energy rate; Water; Oil; Mass flow rate; Temperature

ABSTRACT

The main aim of this research was to develop a mathematical model of heat and mass balance of pre-conditioning and extrusion stages to predict the temperature, moister content and energy requirement of the feed production at different heating temperatures and feeding rates. To achieve that, the effect of temperature and mass flow rate of water and oil in preconditioning on energy rate of preconditioning, mass flow rate of production, mass fraction of moisture of production, and energy rate of product were studied. The results indicate that the energy rate of preconditioning ranged from 523.4 to 8164.7 kJ h-1 and 209.4 to 3266.3 kJ h-1 for water and oil, respectively, the energy rate carried by water injection into extruder increased from 352.5 to 916.5 kJ h-1. The mass flow rate of production increased from 144 to 174, 133 to163 and 119 to179 kg h-1 for water, oil and water and oil, respectively. The mass of moisture of production ranged from 0.2 to 0.34, 0.32 to 0.26, and 0.24 to 0.3 kg h-1 for water, oil and water and oil, respectively. The temperature of product ranged from 159 to 174, 180 to163 and 185 to179 °C for water, oil and water and oil, respectively. The energy rate of product ranged from 52590 to 60795.3, 54616 to 57672.9 and 50708.2 to 61970.3 kJ h-1 when the temperatures increased from 25 to 65°C, respectively, at 5 and 30 kg h-1 mass flow rate.

1. INTRODUCTION

Extrusion is a process that converts raw material into a product with desired shape and form by forcing the material through a small opening using pressure. The process involves a series of unit operations such as mixing, kneading, shearing, heating, cooling, shaping and forming. Many food products are manufactured by extrusion cooking a process that uses both thermal energy and pressure to convert raw food ingredients into popular products such as breakfast cereals, pastas, pet foods, snacks and meat products **(Singh and Heldman, 2009 and Kaddour, 2018)**.

Navale *et al.* (2015) reported that extrusion-cooking is increasing in the global agro-food processing industry, particularly in the food and feed sectors. It is a high-temperature, short-time process in which moistened, expansive, starchy and protenacious raw material is used. Food materials are plasticized and cooked in a minute by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions. It is a multi-step, multi-function thermal or mechanical process, has permitted a large number of food applications. Beneficial changes in the bioavailability as well as in the content of nutrients may take place during extrusion.

The feed cost may correspond up to 70% of the fish meat production cost of a fish breeding station **(Magliano, 2007 and Pacheco *et al.,* 2011)**. Production of high quality floating aquatic feed has in recent years accounted more than 65% of the market needs of fish feed. Most of fish feed factories have tended to develop their production lines by adding extrusion units to produce floating fish feed after increasing demand from farmers for this type of feed for many reasons, such as: the high conversion rates than sinking feed , decreased the consumed amounts of fish feed in aquaculture farms about 30%, easy to follow the fish vitality during feeding process and reduced the chances of infection by fish diseases **(Schoeff, 1994, Navale *et al.*, 2015 and Kaddour, 2018)**.

Temperature is one of the most important factors in steam-conditioning, which affects the pellet quality, nutritional quality and feeding value of animals **(Selle *et al.,* 2013 and Park *et al.,* 2013)**. In the process of conditioning, the characteristics of the pellets and the structure of the main nutrients, such as starch and protein, will change with the conditioning temperature. An appropriate conditioning temperature will increase starch gelatinization and hardness, which may promote the growth performance and digestibility of animals **(Kannadhason *et al.,* 2011, Lundblad *et al.,* 2012 and Lewis *et al.,* 2015)**. The frictional heat generated in the mechanical press due to compression and extrusion helps to activate many of the biomass components. For some densification systems, such as screw extruder, external heat is also provided. Various components of the biomass interact differently by the application of pressure and temperature in the presence of moisture **(Tumuluru *et al.,* 2011)**. **Naga, *et al.* (2018)** and **Martin *et al*. (2019)** indicated that the influence of extruder barrel temperature on the extruder response and pellet quality parameters was generally higher than the impact of screw speed in the range investigated. Expansion is the most relevant pellet production parameter because it influences quality characteristics such as the sinking velocity, bulk density or specific hardness.

Moreover, the heat transfer is also governed by the flow patterns and the flow conditions, i.e., mass transfer and mixing **(Wang *et al.,* 2010)**. In general, mixing contributes to enhanced mass transfer, and further improves heat transfer and distributes physical attributes of individual components more uniformly including temperature and viscosity. **Monchatre *et al.* (2015)** investigated the temperature and frictional heat development (viscous dissipation) in a reciprocating single-screw extruder. Results indicated that a high Nusselt number is probably related to the disturbing flow (induced by the pin elements) and the pulsating flow (induced by the axial movement of the screw) to facilitate distributive mixing and active convection heat transfer **(Dhanasekharan *et al.*, 2003 and Teixeira *et al.*, 2012)**.

Kuzyaev (2005) developed a mathematical model for the optimization of mass and heat transfer processes in the working channel of extruders, considering the changes in the geometrical and technological characteristics. **Spina *et al.* (2017)** simulated the crystallization of isotactic polypropylene (PP) with different shear regimes and results indicated that flow had an important influence on the crystallization during polymer melting and solidification of PP. In one of our earlier works, we proposed a novel torsional screw geometry with twisted grooves, namely a torsion element (TOE), by adapting the field synergy principle to induce torsional flow in the working channel of the screw plasticization unit. The proposed design has been simulated and proved to have excellent heat transfer and mixing properties compared to a standard (STD) screw geometry **(Wang *et al.*, 2010, Jian *et al.*, 2017 and 2018)**.

There is a lack of information in literature about the thermal behavior of heat and mass transfer during the extrusion stage especially pre-conditioning and extrusion stage in floating feed production therefore, the main aim of this study is to optimize the most effective factors on the extruder performance that could be achieved by studying the mass flow rate and cooking temperature on the product temperature, product moisture and energy consumption.

2. MODEL DEVELOPMENT

Fish feed extruder is a high temperature short-time bio-reactor which can transform a variety of raw ingredients into pellets for production of healthy wholesome fish feed. It is one of the prominent developments in fish farming which contributes to the huge step forward in aquaculture. Fish feed extruder comprises of hopper, a barrel which houses, the screw conveyor, the cutting knife, the die, a heater etc. It can be divided into wet and dry type mill. They both can produce floating fish feed pellets, slowing sinking pellets and sinking feed pellets. Fig. (1) showed a schematic diagram of floating feed extrusion process.

2.1. Model assumptions:

The assumptions of the model are the following:

- The effect of changing inputs temperatures is neglected on changing enthalpy, protein denaturization and starch gelatinization.
- Changing effect of the work time work on motor drive.
- In this case, we are working with steady state processes, therefore, there is no accumulation in the system.
- This study may include preconditioner and extruder barrel until getting the product

2.2. Governing equations:

2.2.1. Heat balance equation:

$$\mathrm{Qdr} + \mathrm{Qwp} + \mathrm{Qsp} + \mathrm{Qop} + \mathrm{Qwe} + \mathrm{Qse} + \mathrm{Qme} - \mathrm{Qsg} - \mathrm{Q}pd - \mathrm{Qe} = 0 \quad (1)$$

Where:

Q_{dr}	Energy rate carried by dry recipe, kJ h^{-1}
Q_{wp}	Energy rate carried by water injected into the preconditioner, kJ h^{-1}
Q_{sp}	Energy rate carried by steam injected into the preconditioner, kJ h^{-1}
Q_{op}	Energy rate carried by oil injected into the preconditioner, kJ h^{-1}
Q_{we}	Energy rate carried by water injected into the extruder barrel, kJ h^{-1}
Q_{se}	Energy rate carried by steam injected into the extruder barrel, kJ h^{-1}
Q_{me}	Mechanical energy rate, kJ h^{-1}

Q_{sg}	Energy rate consumed by starch gelatinization, kJ h^{-1}
Q_{pd}	Energy rate consumed by protein denaturation, kJ h^{-1}
Q_e	Energy content of the product at a specific point in the system, kJ h^{-1}

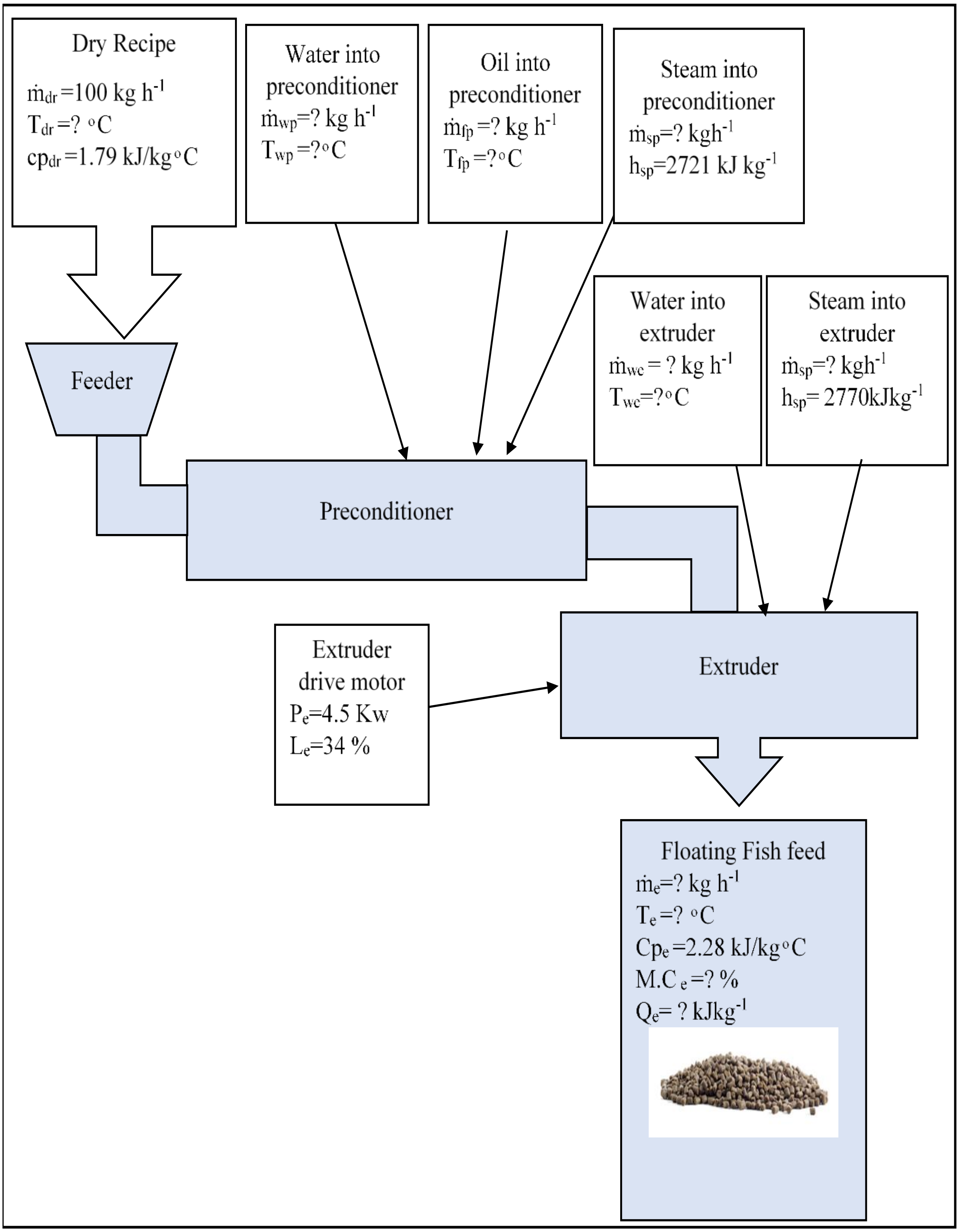


Figure (1): Schematic diagram of the floating feed extrusion process.

2.2.1.1. Energy content of the product at a specific point in the system:

$$(\dot{m}dr * cpdr * Tdr) + (\dot{m}wp * cpwp * Twp) + (\dot{m}sp * hsp) + (\dot{m}op * cpop * Top) + (\dot{m}we * cpwe * Twe) + (\dot{m}se * hse) + (le * pe * 36) - (\dot{m}e * Xce * \Delta Xsg * \Delta hsg) - (\dot{m}e * Xpe * \Delta Xpd * \Delta hpd) - Qe = 0 \qquad (2)$$

$$Qe = (\dot{m}dr * cpdr * Tdr) + (\dot{m}wp * cpwp * Twp) + (\dot{m}sp * hsp) + (\dot{m}op * cpop * Top) + (\dot{m}we * cpwe * Twe) + (\dot{m}se * hse) + (le * pe * 36) - (\dot{m}e * Xce * \Delta Xsg * \Delta hsg) - (\dot{m}e * Xpe * \Delta Xpd * \Delta hpd) \qquad (3)$$

$$Qe = \dot{m}e * cpe * Te \qquad (4)$$

$$Te = \{(\dot{m}dr * cpdr * Tdr) + (\dot{m}wp * cpwp * Twp) + (\dot{m}sp * hsp) + (\dot{m}op * cpop * Top) + (\dot{m}we * cpwe * Twe) + (\dot{m}se * hse) + (le * pe * 36) - (\dot{m}e * Xce * \Delta Xsg * \Delta hsg) - (\dot{m}e * Xpe * \Delta Xpd * \Delta hpd)\} / \{\dot{m}e * cpe\} \qquad (5)$$

Where:

$\dot{m}_{dr}$	Mass flow rate of dry recipe to system, kg h^{-1}
$\dot{m}_{wp}$	Mass flow rate of water to the preconditioner, kg h^{-1}
$\dot{m}_{op}$	Mass flow rate of oil to the preconditioner, kg h^{-1}
$\dot{m}_{sp}$	Mass flow rate of steam to the preconditioner, kg h^{-1}
$\dot{m}_{we}$	Mass flow rate of water to the extruder, kg h^{-1}
$\dot{m}_{se}$	Mass flow rate of steam to the extruder, kg h^{-1}
$\dot{m}_{e}$	Total mass flow rate of material in extruder, kg h^{-1}
C_{pdr}	Heat capacity of dry recipe, kJ kg^{-1} K^{-1}
c_{pw}	Heat capacity of water =4.187 kJ kg^{-1} K^{-1}
c_{ps}	Heat capacity of steam in preconditioning =2.721 kJ kg^{-1} K^{-1}
c_{po}	Heat capacity of oil =1.675 kJ kg^{-1} K^{-1}
C_{pe}	Heat capacity of material in extruder barrel, kJ kg^{-1} K^{-1}
L_e	Indicated load on drive motor, %
P_e	Rated power of extruder drive motor=4.5 kW
Xpe	Mass fraction of protein in extruder barrel for product
Xce	Mass fraction of carbohydrate in extruder barrel for product
Δxsg	Mass fraction of gelatinized starch (x_{sgout}- x_{sgin})
$\Delta h^{\circ}sg$	Heat of reaction for starch gelatinization, kJ kg^{-1}
Δx pd	Mass fraction of denatured protein (x_{sgout}- x_{sgin})
$\Delta h^{\circ}pd$	Heat of reaction for protein denaturization, kJ kg^{-1}
Te	Temperature of material in extruder, K

2.2.1.2. Heat Capacity:

While it may be possible to locate or measure specific heat capacities for the ingredients used in the extruder, it may be more practical to calculate it from the following equation: **Riaz (2000)**

$$C_p = 1.424\ X_c + 1.549\ X_p + 1.675\ X_f + 0.837\ X_a + 4.187\ X_w \qquad (6)$$

Where:

X_c	mass fraction of carbohydrate
X_p	mass fraction of protein
X_f	mass fraction of fat
X_a	mass fraction of ash
X_w	mass fraction of water

2.2.1.3. **Calculation of temperature of material in extruder:**

$$\mathrm{Te} = \frac{Qe}{\dot{\mathrm{m}}\mathrm{e}} * \mathrm{cpe} \tag{7}$$

2.2.2. Mass balance equation:

Using ṁ to indicate mass flow rate per unit time as the following equation:

$$\sum\dot{m}_{in} - \sum\dot{m}_{out} = \Delta m_{sys} \tag{8}$$

Where:

$\sum m_{in}$	Sum of all incoming mass flows, kg h^{-1}
$\sum m_{out}$	Sum of all outgoing mass flows, kg h^{-1}
Δm_{sys}	Accumulation of mass in the system, kg h^{-1}

$$\dot{m}_{dr} * X_{m\,dr} + \dot{m}_{w_P} + \dot{m}_{s_P} + \dot{m}_{we} + \dot{m}_{se} - \dot{m}_{slp} - \dot{m}_e * \mathrm{X\,M.c.\ e} = 0 \tag{9}$$

Use X to indicate the mass fraction of a specific component. In this case, X_m indicates mass fraction of moisture or water.

Value for X will always be less than or equal to 1.0. Assume $\dot{m}_{slp} = 0$, solve the above equation for X_{me}:

$$X\ M.c.e = \frac{\dot{m}_{dr} * X_{m\,dr} + \dot{m}_{w_P} + \dot{m}_{s_P} + \dot{m}_{we} + \dot{m}_{se}}{\dot{m}_e} \tag{10}$$

$$\dot{m}_e = \dot{m}_{dr} + \dot{m}_{w_P} + \dot{m}_{s_P} + \dot{m}_{we} + \dot{m}_{se} \tag{11}$$

2.2.2.1. **The carbohydrate content:**

$$\sum\dot{m}_{in} - \sum\dot{m}_{out} = \Delta m_{sys} \tag{12}$$

A component mass balance on carbohydrate:

$$\dot{m}_{dr} \cdot x_{c\,dr} - \dot{m}_e \cdot x_{ce} = 0 \tag{13}$$

$$Xce = \frac{\dot{m}_{dr} \cdot x_{C\,dr}}{\dot{m}_e} \tag{14}$$

2.2.2.2. **The protein contents**

$$\sum\dot{m}_{in} - \sum\dot{m}_{out} = \Delta m_{sys} \tag{15}$$

A component mass balance on protein:

$$\dot{m}_{dr} \cdot x_{p\,dr} - \dot{m}_e \cdot x_{pe} = 0 \tag{16}$$

$$Xpe = \frac{\dot{m}_{dr} \cdot x_{p\,dr}}{\dot{m}_e} \tag{17}$$

2.2.2.3. The fat contents

$$\sum\dot{m}_{in} - \sum\dot{m}_{out} = \Delta m_{sys} \tag{18}$$

A component mass balance on fat:

$$\dot{m}_{dr} \cdot x_{f\,dr} + \dot{m}_{fp} - \dot{m}_e \cdot x_{fe} = 0 \tag{19}$$

$$Xfe = \frac{\dot{m}f\dot{p} + m_{dr} \cdot x_{f\,dr}}{\dot{m}_e} \tag{20}$$

2.2.2.4. The ash contents

$$\sum\dot{m}_{in} - \sum\dot{m}_{out} = \Delta m_{sys} \tag{21}$$

A component mass balance on ash:

$$\dot{m}_{dr} \cdot x_{a\,dr} - \dot{m}_e \cdot x_{ae} = 0 \tag{22}$$

$$Xae = \frac{\dot{m}_{dr} \cdot x_{a\,dr}}{\dot{m}_e} \tag{23}$$

All computational procedures of the model were carried out using Excel spreadsheet. The computer program consisted of two parts in addition to the input parts. The first part was devoted to heat balance for predicting the temperature and energy rate of preconditioning. The second part was devoted to mass balance for predicting moisture content and mass fraction of moisture of production. Figure (2) shows the flowcharts of the model steps and sequences. Table (1) shows the parameters used in the model.

Table (1): The parameters used in the heat and mass balance according to **Riza (2000)**.

Parameter	Units	Value
Specific heat of water, cp_w	kJ kg^{-1} $^oC^{-1}$	4.187
Specific heat of oil, cpo	kJ kg^{-1} $^oC^{-1}$	1.675
Enthalpy of steam into preconditioner, hsp	kJ kg^{-1}	2721
Enthalpy of steam into extruder, hse	kJ kg^{-1}	2770
Heat capacity of carbohydrate	kJ kg^{-1} $^oC^{-1}$	0.31328
Heat capacity of protein	kJ kg^{-1} $^oC^{-1}$	0.86744
Heat capacity of fat	kJ kg^{-1} $^oC^{-1}$	0.1675
Heat capacity of ash	kJ kg^{-1} $^oC^{-1}$	0.00837
Heat of reaction for protein denaturization, $\Delta h^o pd$	kJ kg^{-1}	95
Heat of reaction for starch gelatinization, $\Delta h^o sg$	kJ kg^{-1}	14
Mass fraction of carbohydrate in dry recipe, Xc dr	--	0.22
Mass fraction of protein in dry recipe, Xp dr	--	0.56
Mass fraction of fat in dry recipe, Xf dr	--	0.1
Mass fraction of ash in dry recipe, Xa dr	--	0.01
Mass fraction of denatured protin in, xpdin	--	0.5
Mass fraction of denatured protin out, xpdout	--	0.95
Mass fraction of gelatinized starch in, xsgin	--	0.17
Mass fraction of gelatinized starch out, xsg	--	0.9
Mass fraction of moisture in dry recipe, Xm	--	0.1
The heat capacity for dry recipe	kJ kg^{-1} $^oC^{-1}$	1.775

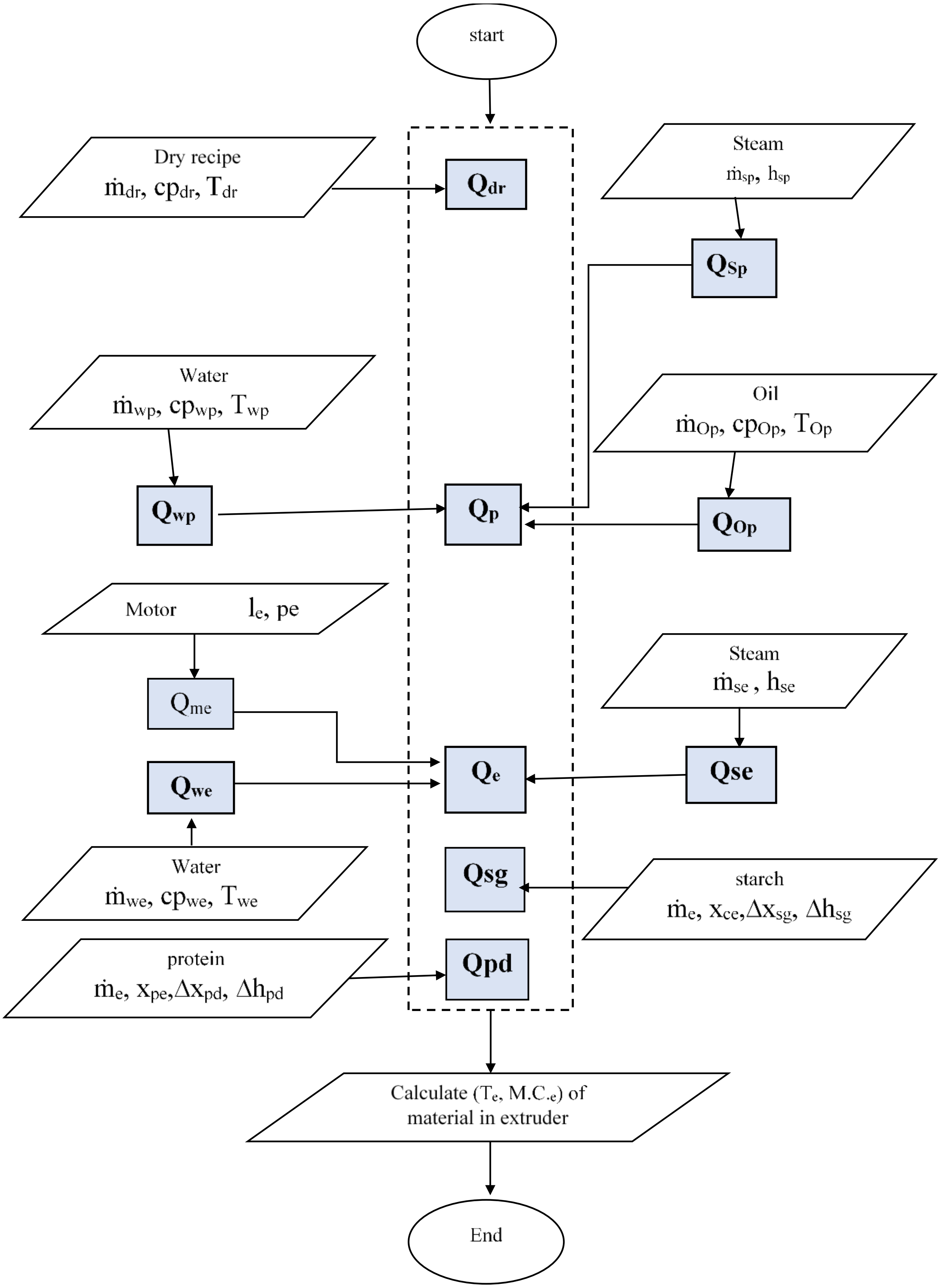


Figure (2): Flow diagram of the floating feed extrusion process

3. RESULTS AND DISCUSSIONS

3.1. Model experimentation

The most factors affecting the extruder performance and energy balance were studied. The effect of temperature and mass flow rate of water, oil and water/oil in preconditioning on energy rate, mass flow rate of production, mass fraction of moisture of production, temperature of product and energy rate of product.

3.1.1. Effect of temperature of water and oil in preconditioning on energy rate of preconditioning

Figure (3) shows the predicted energy rate of preconditioning at different temperatures of water/oil (25, 30, 35, 40, 45, 50, 55, 60 and 65°C) and different mass flow rates of water/oil (5, 10, 15, 20, 25, and 30 kg h^{-1}). The results indicate that the energy rate of preconditioning increases with increasing water/oil temperature and mass flow rate. It could be seen that, when the temperatures of water and oil increased from 25 to 65°C, the energy rate of preconditioning for water increased from 523.4 to 1360.8, 1046.8 to 2721.6, 1570.1 to 4082.3, 2093.5 to 5443.1, 2616.9 to 6803.9 and 3140.3 to 8164.7 kJ h^{-1} at 5, 10, 15, 20, 25 and 30 kg h^{-1} mass flow rate for water/oil, respectively. The results also indicate that, when the temperatures of water and oil increased from 25 to 65°C, the energy rate of preconditioning for oil increased from 209.4 to 544.4, 418.8 to 1088.8, 628.1 to 1633.1, 837.5 to 2177.5, 1046.9 to 2721.9 and 1256.3 to 3266.3 kJ h^{-1} at 5, 10, 15, 20, 25 and 30 kg h^{-1} mass flow rate for water/oil, respectively.

The results also indicate that the energy rate of preconditioning for water was higher than those of the energy rate of preconditioning for oil. It could be seen that the energy rate of preconditioning for water and oil were 1360.8 and 544.4, 2721.6 and 1088.8, 4082.3 and 1633.1, 5443.1 and 2177.5, 6803.9 and 2721.9 and 8164.7 and 3266.3 kJ h^{-1} at 5, 10, 15, 20, 25 and 30 kg h^{-1} mass flow rate for water/oil, respectively, at 65°C temperature of water and oil.

The multiple regression analysis was carried out to find a relation between energy rate of preconditioning and both mass flow rate and temperature of water and oil in preconditioning. Equation (24) shows the most appropriate form for the relationship between energy rate of preconditioning and mass flow rate and temperature of water in preconditioning. Equation (25) shows the most appropriate form for the relationship between energy rate of preconditioning and mass flow rate and temperature of oil in preconditioning. The forms obtained were follows:

$$Q_p=188\,\dot{m}_w+62.8\,T_w-2826.21 \qquad \text{for water} \qquad R^2=0.932 \tag{24}$$

$$Q_p=-0.9\,\dot{m}_o+0.08\,T_o+175.4 \qquad \text{for oil} \qquad R^2=0.932 \tag{25}$$

Where:

Q_p Energy rate of preconditioning, kJ h^{-1}

$\dot{m}_w$ Mass flow rate of water in preconditioning, kg h^{-1}

T_w Temperature of oil in preconditioning, °C

$\dot{m}_o$ Mass flow rate of oil in preconditioning, kg h^{-1}

T_o Temperature of oil in preconditioning, °C

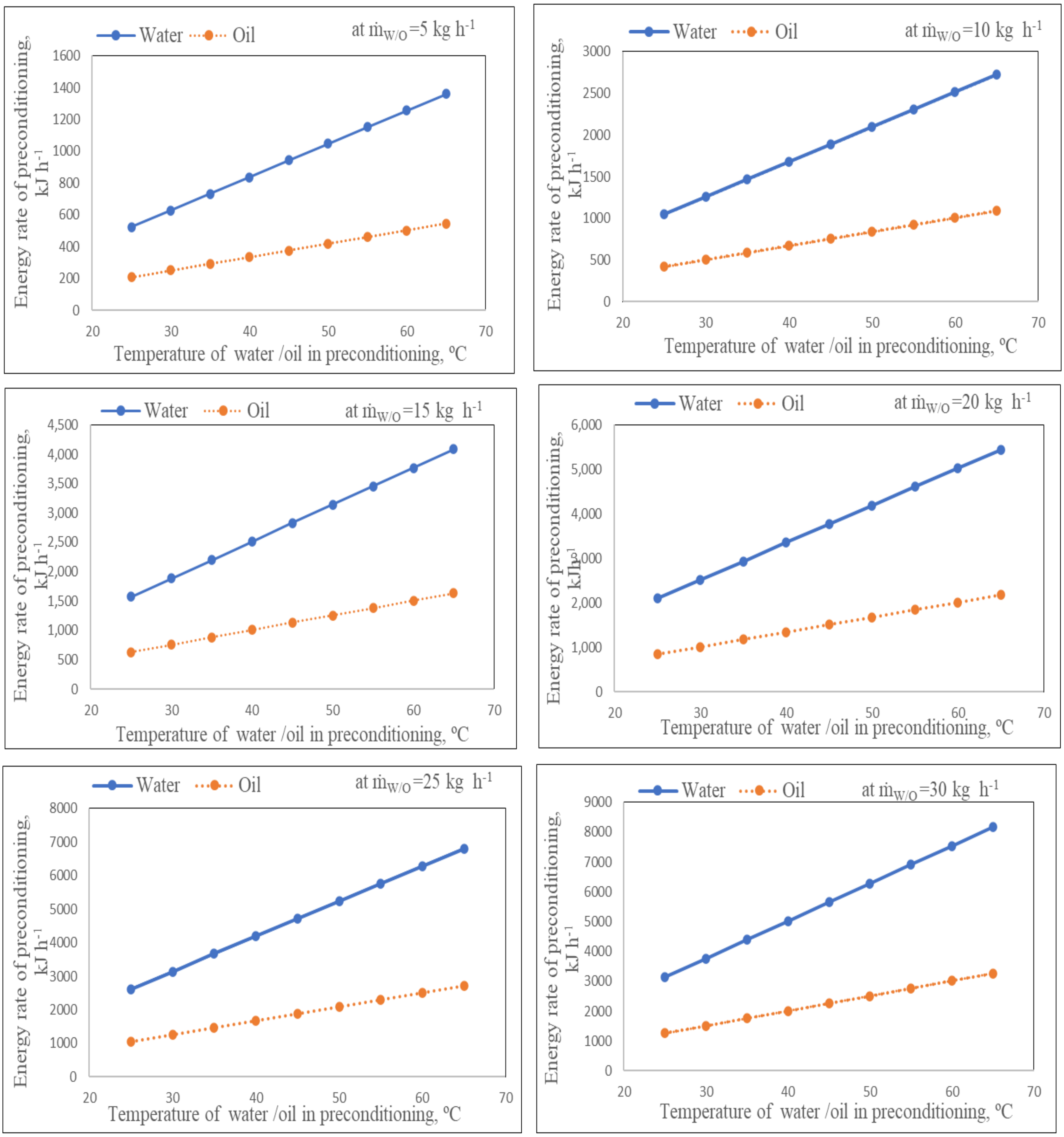


Figure (3): The predicted energy rate of preconditioning at different temperatures of water and oil.

3.2. Effect of temperature of water in preconditioning on energy requirement for water injection into extruder

Figure (4) shows the predicted energy requirement for water injection into extruder at different temperatures of water (25, 30, 35, 40, 45, 50, 55, 60 and 65°C) and different mass flow rates of water/oil (5, 10, 15, 20, 25, and 30 kg h^{-1}). The results indicate that the energy requirement for water injection into extruder increases with increasing water temperature and mass flow rate. It could be seen that, when the temperatures of water increased from 25 to 65°C, the energy for water injection into extruder increased from 352.5 to 916.5, 875.9 to

2277.3, 1399.3 to 3638.1, 1922.6 to 4614.3, 2446.1 to 6359.6, 2969.4 to 7720.4 and 3492.8 to 9081.2 kJ h^{-1} at 5, 10, 15, 20, 25 and 30 kg h^{-1} mass flow rate for water, respectively.

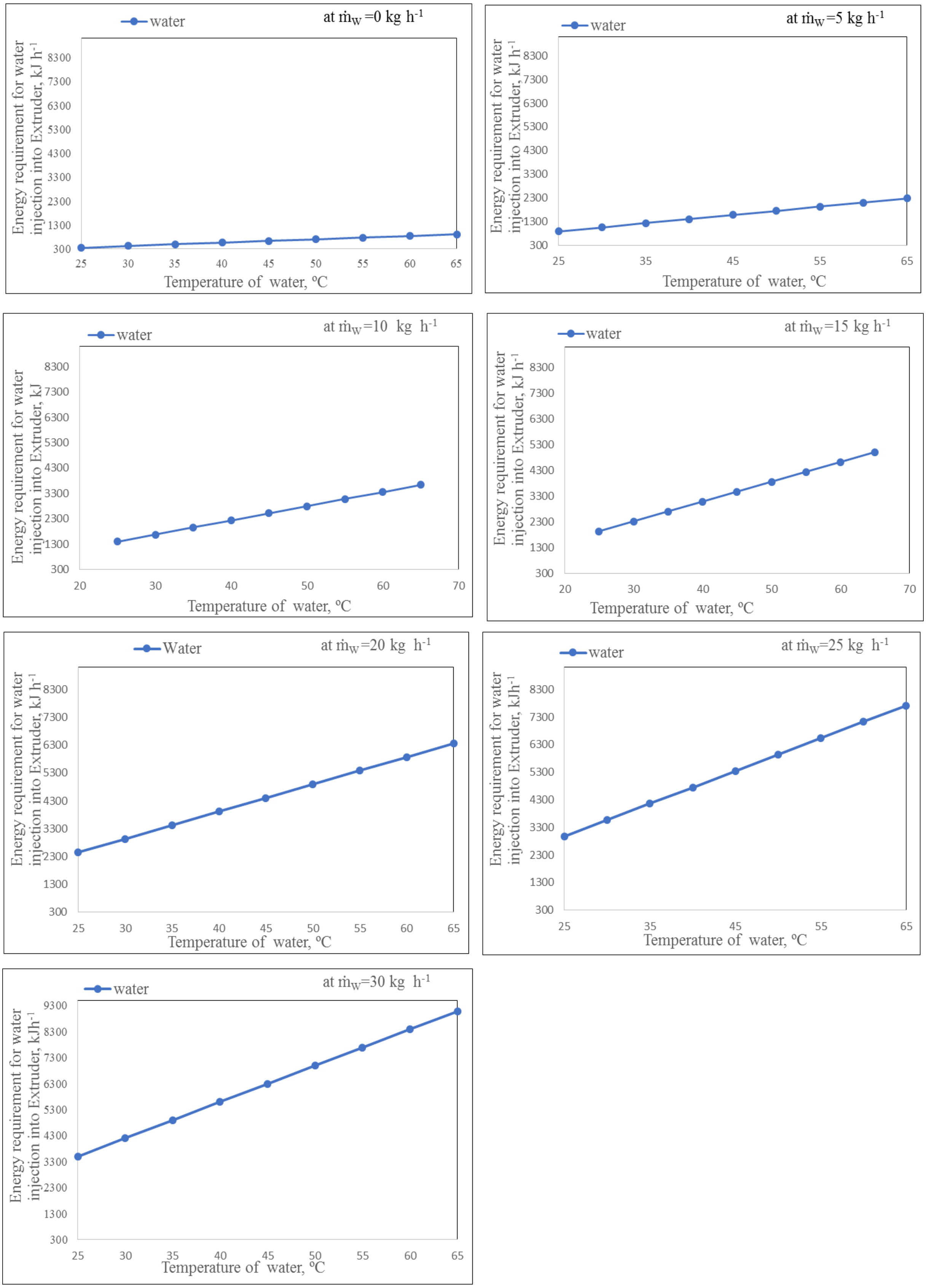


Figure (4): The predicted energy rate carried by water injection into extruder at different temperatures of water

Multiple regression analysis was carried out to obtain a relationship between the energy requirements for water injection into extruder as dependent variable and different water temperature and mass flow rate of water as independent variables. The best fit for this relationship is presented in the following equation:-

$$ER = 188\,\dot{m}_w + 62.8T - 2826.21 \qquad R^2 = 0.93 \qquad (26)$$

Where:

ER Energy requirement for water injection into extruder, kJ h^{-1}

3.3 Effect of flow rate of water and oil in preconditioning on mass flow rate of production

Figure (5) shows the predicted mass flow rate of production at different mass flow rate of water/oil in preconditioning (0, 5, 10, 15, 20, 25 and 30 kg h^{-1}). The results indicate that the mass flow rate of production is constant with increasing mass flow rate of water, oil and water and oil in preconditioning at the same mass flow rate water and oil. It also indicates that it recorded 144, 149, 154, 159, 164, 169 and 174 kg h^{-1}, 133, 138, 143, 148, 153, 158 and 163 kg h^{-1},119,129,139,149,159,169,179 kg h^{-1} for water, water and oil and oil, respectively at flow rate for both water, water and oil and oil (0, 5, 10, 15, 20, 25 and 30 kg h^{-1}), respectively.

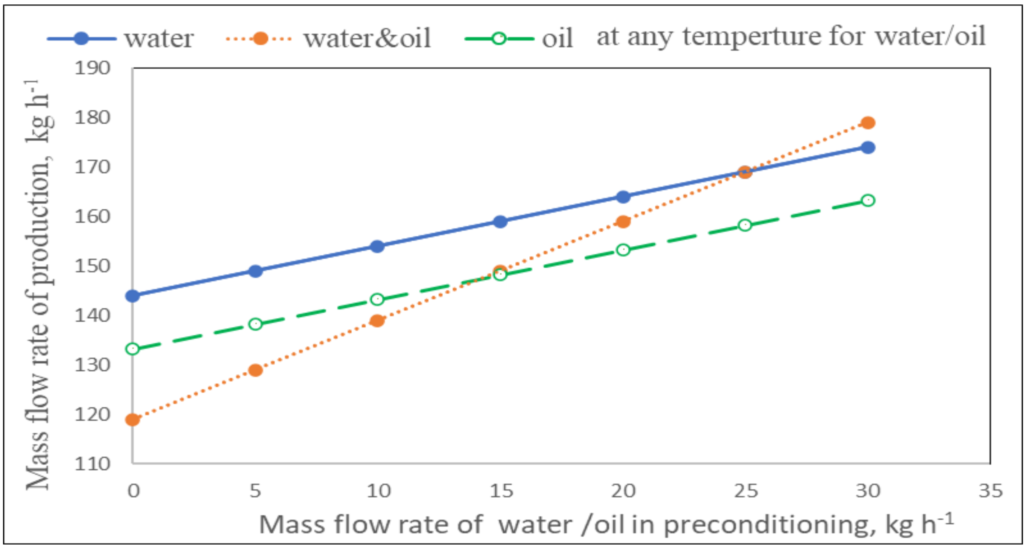


Figure (5): The predicted mass flow rate of production
at different mass flow rate of water and oil in preconditioning.

3.3. Effect of mass flow rate of water /oil in preconditioning on mass fraction of moisture of production

Figure (6) shows the predicted mass fraction of moisture of production at different mass flow rate of water/oil in preconditioning (0, 5, 10, 15, 20, 25 and 30 kg h^{-1}). The results indicate that the mass fraction of moisture of production increases with increasing water and water/oil but it reduces with increasing oil temperature. It also indicates that it recorded 0.2, 0.23, 0.25, 0.28, 0.3, 0.32 and 0.34 kgh^{-1}, 0.32, 0.31, 0.3, 29, 0.28, 0.27 and 0.26 kgh^{-1} and 0.24, 0.26, 0.28, 0.3, 0.31, 0.32 and 0.3 kg$h^{-1}$for water, oil and water and oil, respectively at flow rate for both water, oil and water and oil (0, 5, 10, 15, 20, 25 and 30 kg h^{-1}), respectively.

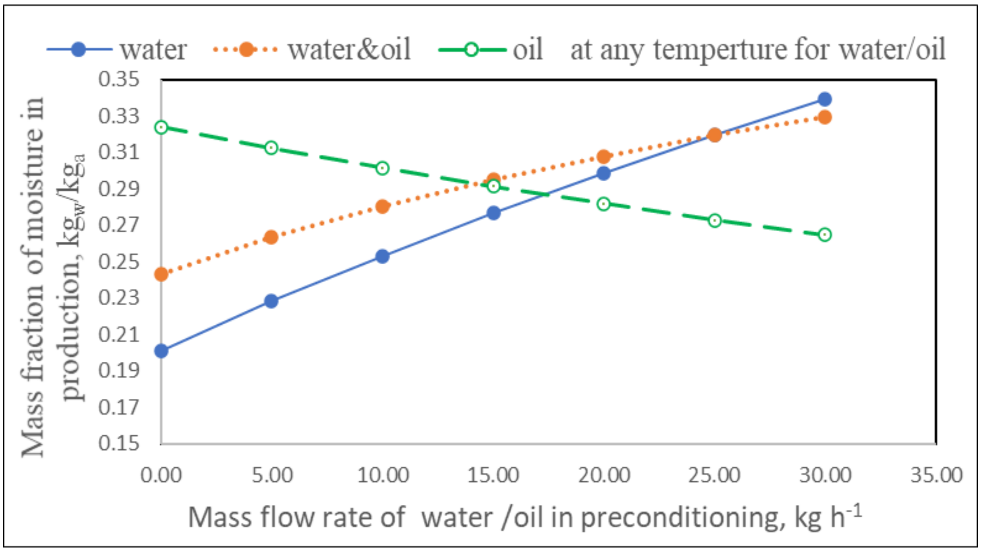


Figure (6): The predicted mass fraction of moisture of production at different mass flow rate of water/oil in preconditioning

3.4. Effect of temperature of water/oil in preconditioning on temperature of product

Figure (7) shows the predicted temperature of product at different temperatures of water and oil in preconditioning (25, 30, 35, 40, 45, 50, 55, 60 and 65°C) and different mass flow rates of water/oil (5, 10, 15, 20, 25, and 30 kg h^{-1}). The results indicate that the temperature of product increases with increasing water, oil and water/oil temperatures.

The results indicate that the product temperature ranged from 159 to 161 and 185 to 187°C for water and water/oil, respectively, and it was constant for oil it recorded 180 °C without adding water or oil (mass flow rate of 0 kg h^{-1}). It also indicates that it ranged from 155 to 159, 173 to 175 and 173 to 179 °C for water, oil and water and oil, respectively at adding 5 kg h^{-1} mass flow rate. It also indicates that it ranged 152 to 158, 168 to 170 and 163 to 172 °C for water, oil and water/oil, respectively at 10 kg h^{-1} mass flow rate. It also indicates that it ranged 149 to 157, 163 to 166 and 154 to 166 °C for water, oil and water/oil, respectively at 15 kg h^{-1} mass flow rate. It also indicates that it ranged 145 to 156, 159 to 162 and 146 to 161 °C for water, oil and water/oil, respectively at adding mass flow rate of 20 kg h^{-1}. It also indicates that it ranged 142 to 155, 154 to 159 and 140 to 156 °C for water, oil and water/oil, respectively at adding mass flow rate of 25 kg h^{-1}. It also indicates that it ranged 139 to 154, 150 to 155 and 134 to 152 °C for water, oil and water/oil, respectively at 30 kg h^{-1} mass flow rate.

The results also indicate that the highest values of product temperature were 159, 175 and 179 °C for water, oil and water/oil, respectively, were found with 5 kg h^{-1} mass flow rate. While, the lowest values of product temperature were 139, 150 and 134 °C for water, oil and water/oil, respectively, were found with 30 kg h^{-1} mass flow rate.

The multiple regression analysis was carried out to find a relation between temperature of product and both mass flow rate and temperature of water and oil in preconditioning. Equation (27) shows the most appropriate form for the relationship between temperature of product and mass flow rate and temperature of water in preconditioning. Equation (28) shows the most appropriate form for the relationship between temperature of product and mass flow rate and temperature of oil in preconditioning.

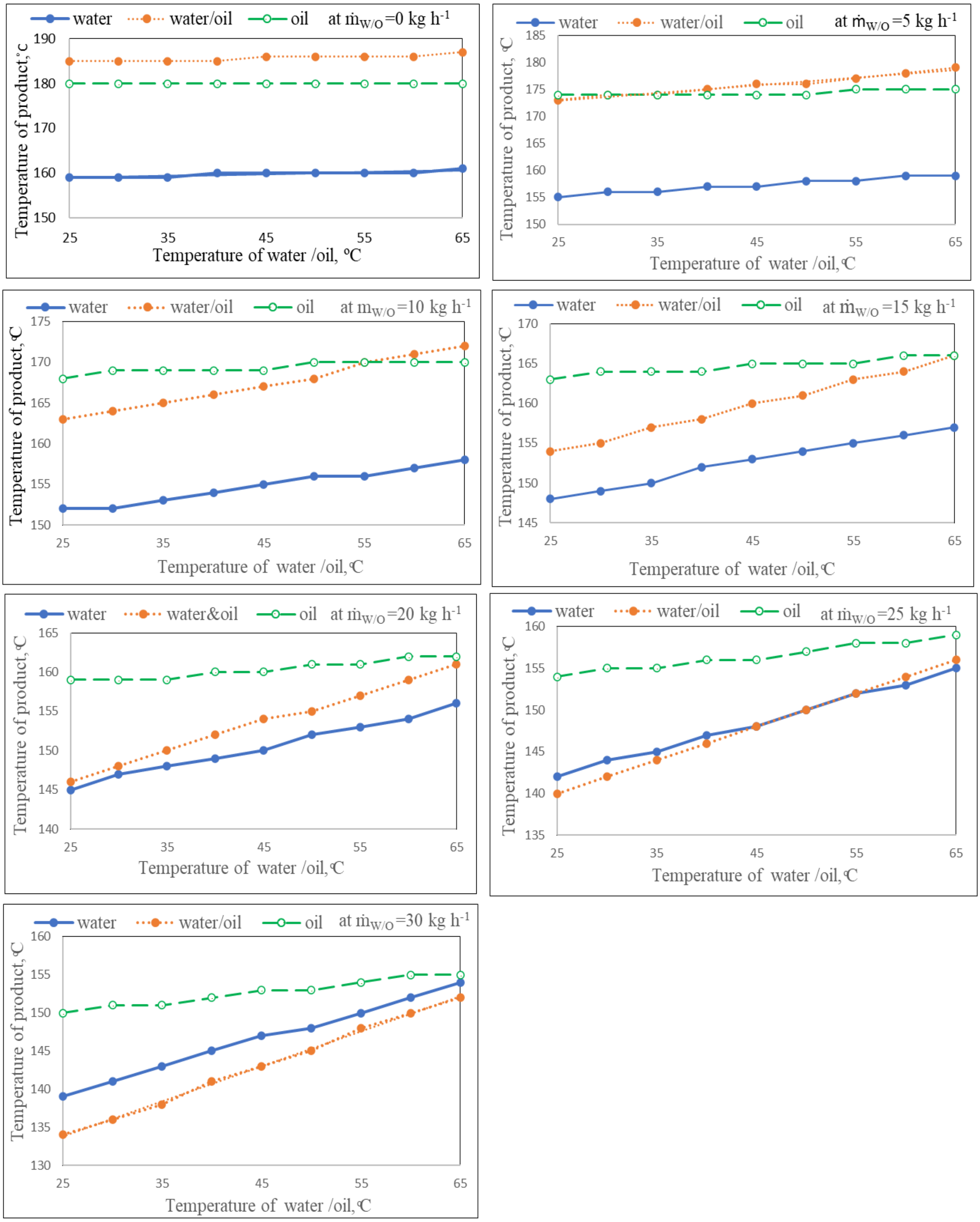


Figure (7): The predicted temperature of product at different temperatures of water and oil in preconditioning

Equation (29) shows the most appropriate form for the relationship between temperature of product and mass flow rate and temperature for both water and oil in preconditioning. The forms obtained were follows:

T_e= -0.44 $\dot{m}_w$ +0.21 T_w +149.9 for water R^2=0.93 (27)

T_e= -0.9 $\dot{m}_o$ +0.08 T_o +175.4 for oil R^2=0.99 (28)

T_e= -1.41 $\dot{m}_{w/o}$ +0.28 $T_{w/o}$ +170.5 for both water and oil R^2=0.97 (29)

Where:

T_e Temperature of product, °C

$\dot{m}_{w/o}$ Mass flow rate for both water and oil in preconditioning, kg h^{-1}

$T_{w/o}$ Temperature for both water and oil in preconditioning, °C

3.5. Effect of temperature of water /oil in preconditioning on energy rate of product

Figure (8) shows the predicted energy rate of product at different temperatures of water/oil in preconditioning (25, 30, 35, 40, 45, 50, 55, 60 and 65°C) and different mass flow rates of water/oil (5, 10, 15, 20, 25, and 30 kg h^{-1}). The results indicate that the energy rate of product increases with increasing water, oil and water/oil temperatures. It also indicates that it ranged from 52066.6 to 52630.6 and 49975.4 to 50539.4 kJ h^{-1} for water and water and oil, respectively, but it was constant for oil it recorded 54406.6 kJ h^{-1} without adding water or oil. It also indicates that it ranged from 52590.0 to 53991.4, 54616.0 to 54951.0 and 50708.2 to 52444.6 kJ h^{-1} for water, oil and water/oil, respectively at adding mass flow rate 5 kg h^{-1}. It also indicates that it ranged from 53113.4 to 55352.2, 54825.4 to 55495.4 and 51440.9 to 54349.7 kJ h^{-1} for water, oil and water/oil, respectively at adding mass flow rate 10 kg h^{-1}. It also indicates that it ranged from 53636.7to 56712.9, 55034.7to 56039.7 and 52173.7 to 56254.9 kJ h^{-1} for water, oil and water/oil, respectively at adding mass flow rate 15 kg h^{-1}. It also indicates that it ranged from 54160.1 to 58073.7, 55244.1 to 56584.1 and 52906.4 to 58160.0kJ h^{-1} for water, oil and water and oil, respectively at adding mass flow rate 20 kg h^{-1}. It also indicates that it ranged from 54683.5 to 59434.5, 55453.5 to 57128.5 and 53639.2to 60065.2kJ h^{-1} for water, oil and water/oil, respectively at adding mass flow rate 25 kg h^{-1}. It also indicates that it ranged from 55206.9 to 60795.3, 55662.9 to 57672.9 and 54371.9 to 61970.3 kJ h^{-1} for water, oil and water and oil, respectively at adding mass flow rate 30 kg h^{-1}. The multiple regression analysis was carried out to find a relation between energy rate of product and both mass flow rate and temperature of water and oil in preconditioning. Equation (30) shows the most appropriate form for the relationship between energy rate of product and mass flow rate and temperature of water in preconditioning. Equation (31) shows the most appropriate form for the relationship between energy rate of product and mass flow rate and temperature of oil in preconditioning. Equation (32) shows the most appropriate form for the relationship between energy rate of product and mass flow rate and temperature for both water and oil in preconditioning. The forms obtained were follows:

Q_e=188.4 $\dot{m}_w$+76.9 T_w+ 48887.89 for water R^2=0.937 (30)

Q_e=75.4 $\dot{m}_o$ +27.9 T_o +53102.1 for oil R^2=0.91 (31)

Q_e=263.8 $\dot{m}_{w/o}$+102 $T_{w/o}$+ 45666.04 for both water and oil R^2=0.936 (32)

Where:

Q_e Energy rate of product, °C

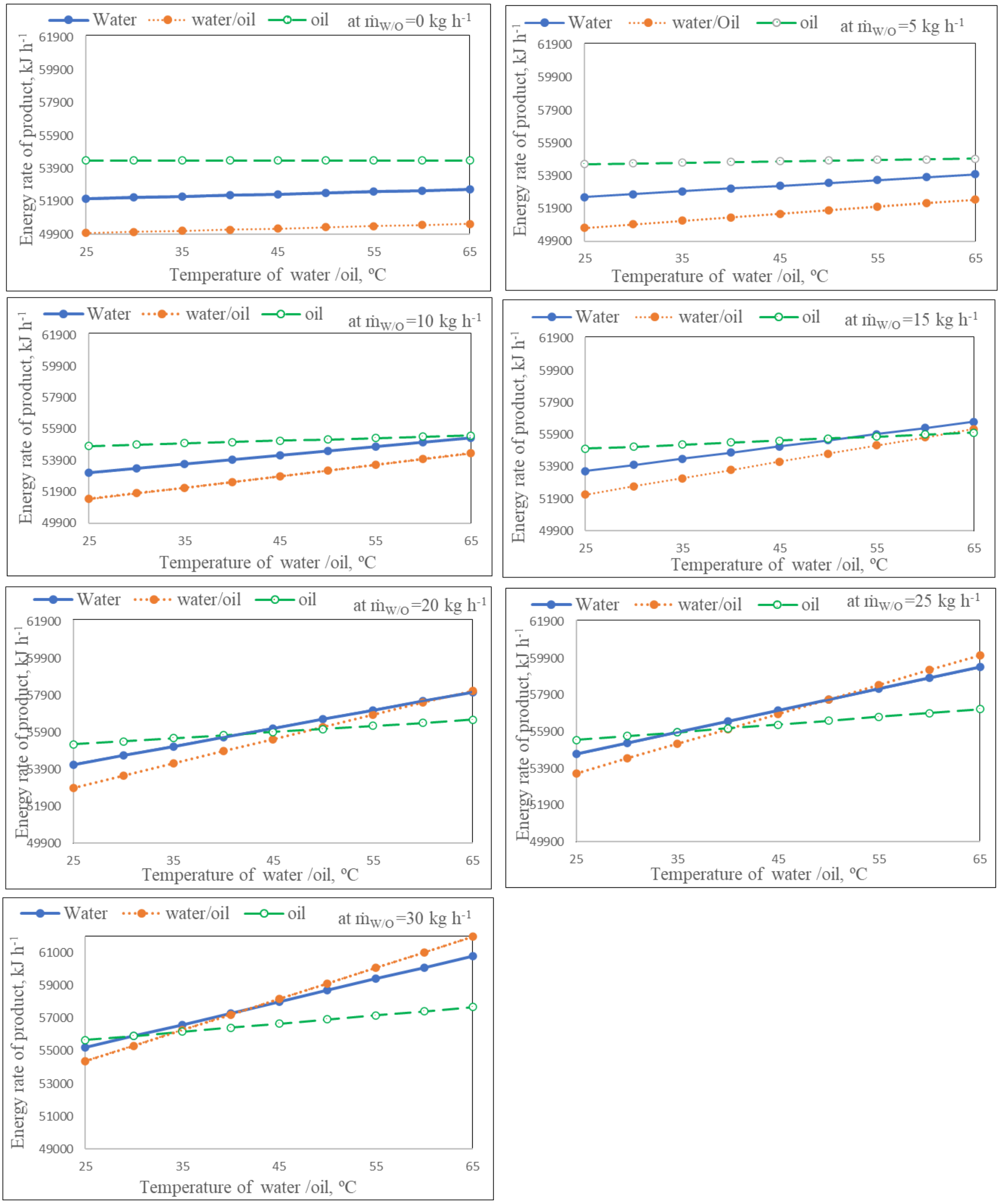


Figure (8): The predicted energy rate of product
at different temperatures of water and oil in preconditioning

4. CONCLUSION

The study was carried out to develop a mathematical model of heat and mass balance of the extrusion process to predict the temperature, water content and energy requirement of the feed production at different heating temperatures and feeding rates. To Achieve that study the effect of different temperatures of water/oil (25, 30, 35, 40, 45, 50, 55, 60 and 65°C) and different mass flow rates of water/oil (5, 10, 15, 20, 25, and 30 kg h^{-1}) on energy rate of preconditioning, energy requirement for water injection into extruder, mass of moisture of production, temperature of product and energy rate of product. The results indicate that the mass flow rate of production is constant with increasing water and oil temperature in preconditioning at the same mass flow rate water and oil. The energy rate of preconditioning ranged from 523.4 to 8164.7 kJ h^{-1} and 209.4 to 3266.3 kJ h^{-1} for water and oil, respectively. The energy requirement for water injection into extruder increased from 352.5 to 916.5 kJ h^{-1}, the mass flow rate of production increased from 144 to 174, 133 to163 and 119 to179 kgh^{-1} for water, oil and water and oil, respectively. The mass of moisture of production ranged from 0.2 to 0.34, 0.32 to 0.26, and 0.24 to 0.3 kgh^{-1} for water, oil and water and oil, respectively. The temperature of product ranged from 159 to 174, 180 to163 and 185 to179°C for water, oil and water and oil, respectively. The energy rate of product ranged from 52590 to 60795.3, 54616 to 57672.9 and 50708.2 to 61970.3 kJ h^{-1} for water, oil and water and oil, respectively, at mass flow rate 5 to 30 kg h^{-1}, when the temperatures of increased from 25 to 65°C.

5. REFERENCES

Dhanasekharan, K.M. and Kokini J.L. (2003). Design and scaling of wheat dough extrusion by numerical simulation of flow and heat transfer. J. Food Eng., 60, 421–430.

Jian, R.R., Yang W.M., Cheng L.S. and Xie P.C. (2017). Numerical analysis of enhanced heat transfer by incorporating torsion elements in the homogenizing section of polymer plasticization with the field synergy principle. Int. J. Heat and Mass Transfer, 115, 946–953.

Jian, R.R., Yang W.M., Cheng L.S. and Xie P.C. (2018). Numerical Simulation on the Enhanced Mixing of Polymer Melt by Single Screw with Torsion Elements in the Homogenizing Section. Polym.-Korea, 42, 910–918.

Kaddour, O. (2018). Factors affecting the floating aquatic feed pellets quality. Misr J. Ag. Eng., 35 (3): 1019 - 1038.

Kannadhason, S., Muthukumarappan K. and Rosentrater K.A. (2011). Effect of starch sources and protein content on extruded aquaculture feed containing DDGS. Food Bioprocess Technol. 4, 282–294.

Kuzyaev, I.M. (2005). Intensification of Heat and Mass Transfer Processes in the Working Channel of Extrusion Machines during Processing of Newtonian Polymer Liquids. Heat Transf. Res., 36, 359–371.

Lundblad, K., Hancock J., Behnke K., McKinney L., Alavi S., Prestlokken E. and Sorensen M. (2012). Ideal digestibility of crude protein, amino acids, dry matter and phosphorous in pigs fed diets steam conditioned at low and high temperature, expander conditioned or extruder processed. Anim. Feed Sci. Technol. 172, 237–241.

Lwis, L.L., Stark C.R., Fahrenholz A.C., Bergstrom J.R. and Jone C.K. (2015). Evaluation of conditioning time and temperature on gelatinized starch and vitamin retention in a pelleted swine diet. J. Anim. Sci. 93, 615–619.

Magliano, R. (2007). Aqüicultura: grande aliada? Faces e Interfaces. Available in: http://www.olharvital.ufrj.br/2006/index.php?id_edic ao=067&codigo=4. Accessed on: 10/06/09.

Martin, A., Raffael O., Alexander G., Heike P.K. and Azad E. (2019). Effect of rapeseed press cake and peel on the extruder response and physical pellet quality in extruded fish feed. Aquaculture, 512: 734316.

Monchatre, B., Raveyre C. and Carrot C. (2018). Influence of the melt viscosity and operating conditions on the degree of filling, pressure, temperature, and residence time in a co-kneader. Polym. Eng. Sci., 58, 133–141.

Naga K., Romano N., Ebrahimi M., Amin S.M.N., Kamarudin M. S., Karami A. and Kumar V. (2018). Improvement of feed pellet characteristics by dietary pre-gelatinized starch and their subsequent effects on growth and physiology in tilapia. Food Chemistry 239 (2018) 1037–1046.

Navale, S.A., Swami S.B. and Thakor N.J. (2015). Extrusion Cooking Technology for Foods: A Review. Journal of Ready to Eat Food, 2(3): 66 - 80.

Pacheco, A.C.W., Gianini R.L., Paulo E.P., Luiz M.D.J. and Paulo R.P. (2011). Modeling of drying and adsorption isotherms of the fish feed. Brazilian archives of biology and technology, Brasil.

Park, B.C., Shinjin, Co., Ltd and Seoul (2013). Effects of extruded and extruded-pelleted corn products partially substituted for unprocessed corn of the starter diet on growth performance and incidence of diarrhea in weanling pigs. J. Anim. Sci. Technol. 55, 109–113.

Riaz, M.N. (2000). Extruders in food applications. CRC press is an imprint of Taylor and Francis Group. http://www.crcpress.com.

Schoeff, R.W. (1994). History of the Formula Feed Industry. In: R.R. McEllhiney, Ed. Feed Manufacturing Technology IV. American Feed Industry Association. Arlington, Virginia: 7.

Selle, P.H., Liu S.Y., Cai J. and Cowieson A.J. (2013). Steam-pelleting temperatures, grain variety, feed form and protease supplementation of medially ground, sorghum-based broiler diets: influences on growth performance, relative gizzard weights, nutrient utilization, and starch and nitrogen digestibility. Anim. Product. Sci. 53, 378–387.

Singh, R.P. and Heldman D.R. (2009). Introduction of food engineering. Fourth edition. Elsevier. Chaina.

Spina, R., Spekowius M. and Hopmann C. (2017). Simulation of crystallization of isotactic polypropylene with different shear regimes. Thermochim. Acta, 659, 44–54.

Teixeira, C., Gaspar-Cunha A. and Covas J.A. (2012). Flow and heat transfer along the length of a co-rotating twin screw extruder. Polym.-Plast. Technol. Eng., 51, 1567–1577.

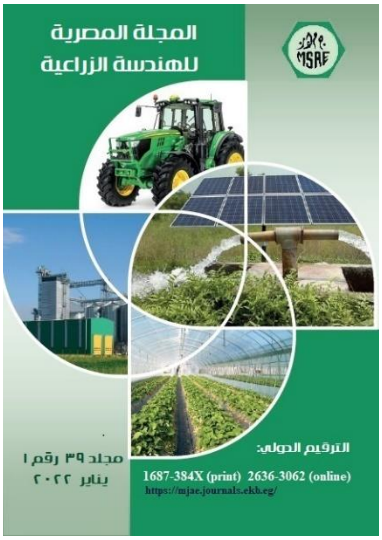
Tumuluru, J.S., Wright C.T., Hess J.R. and Kenney K.L. (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application, Biofuels Bioprod. Biorefin. 5, 683–707.

Wang, C., Bussmann M. and Park C.B. (2010). Numerical Investigation of the Effect of Screw Geometry on the Mixing of a Viscous Polymer Melt. J. Appl. Polym. Sci., 117, 775–784.

نمذجة الاتزان الحراري والكتلي لمرحلتي التهيئة المسبقة والبثق لإنتاج علف الأسماك الطافي

اسلام فوزي العادلى[١]، عادل حامد بهنساوى[٢]، سمير أحمد على[٢]، السيد جمعه خاطر[٣]

[١] مدرس الهندسة الزراعية المساعد - كلية الزراعة بمشتهر - جامعة بنها - مصر.
[٢] استاذ الهندسة الزراعية - كلية الزراعة بمشتهر - جامعة بنها - مصر.
[٣] استاذ الهندسة الزراعية المساعد - كلية الزراعة بمشتهر - جامعة بنها - مصر.



الكلمات المفتاحية:
اتزان حراري؛ اتزان كتلي؛ نموذج رياضي؛ باثق؛ معدل الطاقة.

الملخص العربي

الهدف الرئيسي من هذا البحث هو تطوير نموذج رياضي لاتزان الحرارة والكتلة لمرحلتي التكييف المسبق والبثق من اجل التنبؤ بدرجة الحرارة ومحتوى الرطوبة ومتطلبات الطاقة لإنتاج العلف عند درجات حرارة مختلفة ومعدلات تغذية مختلفة. ولتحقيق ذلك تم دراسة تأثير درجة الحرارة ومعدل التدفق الكتلي للماء والزيت في حالة التكييف المسبق على معدل طاقة التكييف المسبق ومعدل الإنتاجية، والرطوبة في المنتج، ومعدل الطاقة في المنتج النهائي.

تشير النتائج إلى أن معدل الطاقة للتكييف المسبق تراوح من ٥٢٣,٤ إلى ٨١٦٤,٧ كيلوجول/ ساعة و٢٠٩,٤ إلى ٣٢٦٦,٣ كيلوجول/ ساعة للمياه والزيت على التوالي. زاد معدل الطاقة المنقولة عن طريق حقن الماء في الطارد من ٣٥٢,٥ إلى ٩١٦,٥ كيلوجول/ ساعة. زاد معدل التدفق للإنتاج من ١٤٤ إلى ١٧٤ ومن ١٣٣ إلى ١٦٣ ومن ١١٩ إلى ١٧٩ كجم في الساعة للمياه والزيت ثم الماء والزيت معا على التوالي. تراوحت كتلة رطوبة الإنتاج من ٠,٢ إلى ٠,٣٤ و٠,٣٢ إلى ٠,٢٦ و٠,٢٤ إلى ٠,٣ كجم في الساعة للمياه والزيت ثم الماء والزيت على التوالي. وتراوحت درجة حرارة المنتج من ١٥٩ إلى ١٧٤ و١٨٠ إلى ١٦٣ و١٨٥ إلى ١٧٩ درجة مئوية للمياه والزيت ثم الماء والزيت على التوالي. تراوح معدل الطاقة للمنتج من ٥٢٥٩٠ إلى ٦٠٧٩٥,٣ ومن ٥٤٦١٦ إلى ٥٧٦٧٢,٩ ثم من ٥٠٧٠٨,٢ إلى ٦١٩٧٠,٣ عندما زادت درجات الحرارة من ٢٥ إلى ٦٥ درجة مئوية، على التوالي، عند ٥ الى ٣٠ كجم في معدل التدفق الكتلي.