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Investigation of the Performance of Centrifugal Floating Feeder Machine at Different Distribution Angles

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ABSTRACT

An increase in shrimp and lobster farming activities due to export required improvement in the aquacultural farming sector of Kalasin Province, Thailand. A prototype centrifugal floating food feeder machine was designed and constructed to be used on shrimp and lobster farms in Kalasin Province. The feeder was located in the center of a radially placed paper sheet. The main parameter investigated was the distribution angle that can be adjusted inside the feeder. The distribution angle significantly influences the peak density location of food drop and also the maximum density. The peak density location shifted from 6 meters to 12 meters as the distribution angle of the feeder increased from 0º to 10º. As the distribution angle inclined further to 30º and 40º the peak distribution location increased also to 14 meters. Maximum density increased from 1.787 mg/cm^2 to 2.365 mg/cm^2 as the distribution angle changed from 0º to 10º. However, the maximum density decreased to 1.804 mg/cm^2 as the distribution angle increased to 40º. The coefficient of variation and uniformity coefficient ranged from 55.8% to 67.5% and 52.6% to 38.0% at different distribution angles. Statistical analysis through ANOVA demonstrated insignificant differences between data obtained from different distance levels and distribution angles. To provide an advance and a long-range feeding cycle with high uniformity the distribution angle should be set at 30º. The economic analysis revealed the fixed cost of 60,000 baht and labor cost of 20,000 baht giving a payback period of 8 months.

Keywords: Centrifugal machine; Distribution angle; Food feeder; Lobster farming

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1. Introduction

Shrimp and lobster farming has been considered as one of the main aquacultural businesses in Thailand. Among many intense shrimp farming provinces, Kalasin Province in northeast Thailand has emerged as a prominent community for the highly valued shrimp business. Most of the lobster species that are raised are golden claw lobsters and blue lobsters [1]. Irrigation covers the area of 3 districts, namely Yang Talat District, Mueang District, and Huai Mek District. There are approximately 1,147 lobster farms, with an area of 1,333 hectares, and production of 1,670 tons per year. The selling price at the pond ranged between 250 to 300 baht per kilogram and the total value of the business was 415 million baht per year [2].

The successful lobster business is due to an abundant water source in the area and a suitable environment. In addition, providing a job for workers in the provinces reduces their immigration to work in the capital. Labor is easy to find and labor costs are relatively cheap. However, at present the number of lobsters in natural water resources has decreased dramatically. In addition, the demand for lobster consumption has increased in value, according to the increasing population, causing lobster farmers to have higher incomes accordingly.

The most significant aspect of raising lobsters involves the feeding process. At present, lobster farming is a farming system that uses shrimp pellet-feeding technology. There are two feeding methods: sowing shrimp feed by workers and sowing shrimp feed by machines [3]. The use of shrimp food feeders is very popular because they can feed shrimp in various directions, reduce the work time of workers, and increase the convenience of managing the farm system. However, the use of shrimp feeders still encounters operational problems that affect shrimp farming; namely, the distribution of food is not even throughout the shrimp pond and the distribution of shrimp feed is dense at a single width [4, 5]. This prevents the shrimp feed from reaching the edge of the pond. Aditya et al. proposed an automatic feeding system equipped with the Internet of Things (IoT) monitoring and control functions [6].

The automatic system enabled a remote control scheduled feeding routine and a radial feeding position up to 10 meters in a 2,500 m^2 shrimp pond [7, 8]. Automatic feeders that have schedule timing mode can significantly help save electricity costs during operation [2-9]. Open-source software such as Forage Feeder has been successfully employed to help automate feeding tasks to reduce labor costs [10]. A DC motor was developed and programmed using pulse width modulation techniques to release and fill the food storage when the voltage dropped below the threshold point [11]. Other researchers have focused on passive acoustic feeding methods and computer vision to help improve the growth rate of shrimp and lobster [12, 13]. However, most designs are only applicable for short-range feeding and require large capital investment for construction, operation, and maintenance. The prototype developed in this research offers high-accuracy distribution at a lower cost.

2. Objectives

This research is to develop a centrifugal floating lobster feeder to be able to distribute shrimp food evenly and bring technology in conjunction with agriculture by setting the time of the working period. Operators can now define working time and be notified when shrimp food in the feeder runs out. Additionally, this technology can also adjust the distance and distribution of food to suit the size of the shrimp pond to improve its effectiveness and reduce working time. To transfer such technology to lobster farmers, a lobster farm in Kalasin Province will be selected as a model farm. A prototype feeder will be tested to investigate performance.

Due to an increase in productivity, this project can be applied to large-scale industrial farm systems for export in the future.

3. Materials and Methods

This research investigated the impact of distribution angle on the projectile range of the feeder. The first step involved designing the centrifugal floating giant freshwater prawn feeder machine. Consequently, the distribution angle was varied and tested using the feeder machine to investigate the length and density of the distributed food. Data collection proceeded in the next step and if the feeder can uniformly and thoroughly send food around the pond then these data can be analyzed to demonstrate statistical significance as shown in Fig. 1.

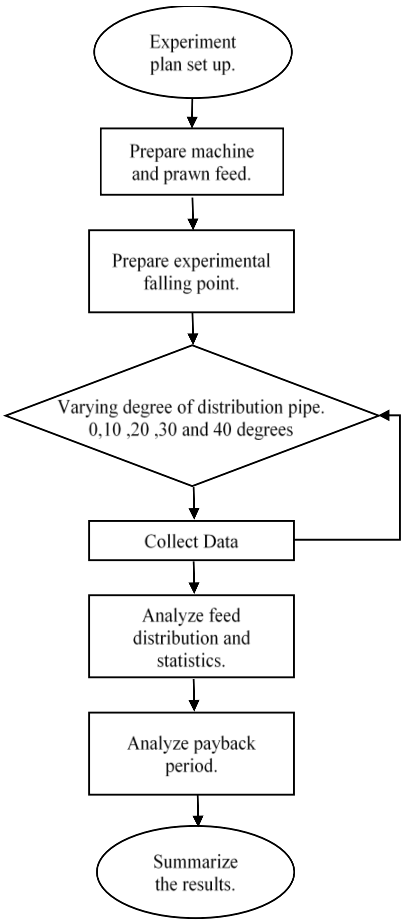


Fig. 1. Flow chart illustrating the methodology and logic followed in this research.

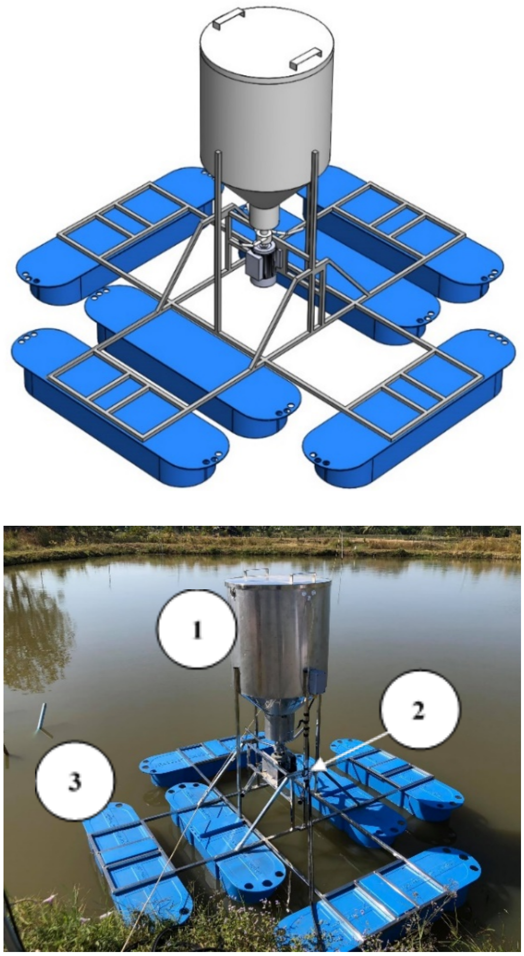


Fig. 2. Shrimp food feeder system entailed 1. food storage, 2. Motor, and 3. Floaters.

3.1 Feeder design

A distribution system of the food feeder was designed, benchmarked, and constructed as a prototype for operation inside a lobster pond as shown in Fig. 2. The feeder consisted of various components including a 170 L conical storage tank, structural supporting section, and the distribution pipe system [12]. The mass of the feeder needed to be designed according to the buoyancy force. To assure the feeder stays above water 6 floaters were used [13]. The feeding distance, the time it takes for food to travel to the designation, and the feeding angle are calculated from the following equation:

$$S_y = S_{(0)y} + U_y t + \frac{1}{2} g t^2, \qquad (3.1)$$

where S_y represents the vertical distance from the feeder (m), $S_{(0)y}$ represents the initial position of the feeder (m), U_y represents the initial vertical velocity component (m/s), g is the gravitational force (m/s^2) and t is the vertical time travel by the food from the feed (s).

Eq. (3.1) illustrated projectile motion with general trajectory which incorporates the range, maximum height, and symmetry of the object in motion. In this model air resistance is neglected, acceleration is constant and the only force acting on the object is gravity.

3.2 Pipe distributor design

The design of the feed distribution pipe as shown in Fig. 3. is a design using the mechanical energy conservation equation to determine the velocity of the feed distribution pipe. In this design, the velocity of the feed distribution tube can be determined in a manner conserving angular momentum where the pivot point is the center of the feed tube or the motor spindle. As a result, we can know the theoretical falling distance of the feed with projectile motion where the motor power is 0.5 Hp and the rotational speed is 1400 rpm.

The distribution of prawn feed in this study was tested by adjusting the angle of the feed spreader at 0, 10, 20, 30, and 40 degrees, respectively, as shown in Fig. 6. Then, the values were calculated by using the conservation of mechanical energy. The theoretical distribution distance at different angles is shown in Fig. 5.

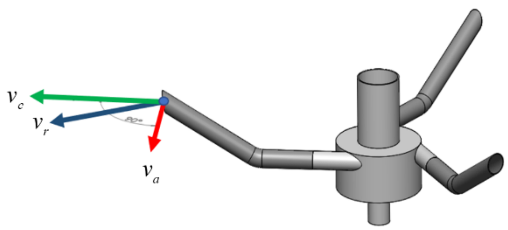


Fig. 3. Appearance of feed distribution pipe and its design using mechanical energy conservation.

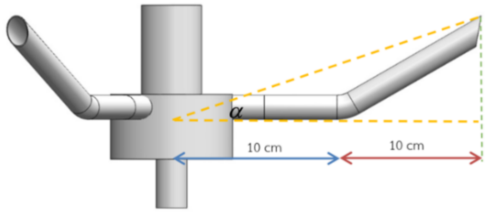


Fig. 4. Angle of prawn feed distribution pipe.

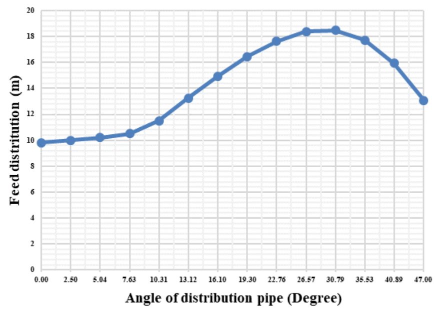


Fig. 5. Relationship between angle and feed distribution in theoretical.

3.3 Performance testing

The food feeder was tested on the ground to observe the angle of distribution and distance traveled by the food from the feeder. Paper sheets were placed radially in different directions from the food feeder in the center. Approximately, 5,000 grams of shrimp food was added to the conical food storage and then distributed radially to different locations and collected by the paper sheets. Consequently, the feeding efficiency of the machine at each angle was compared by weighing the food pellets that have fallen into the designated sampling point. Then the amount of food that falls into weight (grams) per square centimeter was calculated. The results of the distribution of the feed were collected using sampling points with an area of 1 sq.m. per sampling point and there are 10 sampling points per row. Each point has a distance of 2 meters, the distance from the center to the furthest point was 20 meters, and a total of 8 rows surround the feeder as shown in Fig. 6. The dispersion distance chosen was based on the size of the ponds commonly used by farmers, which were 40×40 meters. The prawn feeder test was carried out according to the experimental plan shown in Fig. 7. The equations below were then used to find the coefficient of variation (CV) and the uniformity coefficient (UC).

$$CV = \frac{S.D.}{\overline{X}}, \tag{3.2}$$

where CV represents the coefficient of variation (%), $S.D.$ represents the standard deviation (kg/cm^2), and represents the mean (kg/cm^2).

$$UC = 100 \times \left(1 - \frac{\sum x}{mn}\right), \tag{3.3}$$

where UC represents the uniformity coefficient (%), n represents the number of sampling, m represents the mass of food on the paper sheet (kg/cm^2) and x is the difference between each data point (kg/cm^2).

The efficiency of the feeding machine is calculated by the equation below.

$$\%\,\text{performance} = \frac{x_{ouput}}{x_{input}} \times 100, \tag{3.4}$$

where X_{output} and X_{input} represent the actual length of the feeder and the theoretical length of the feeder.

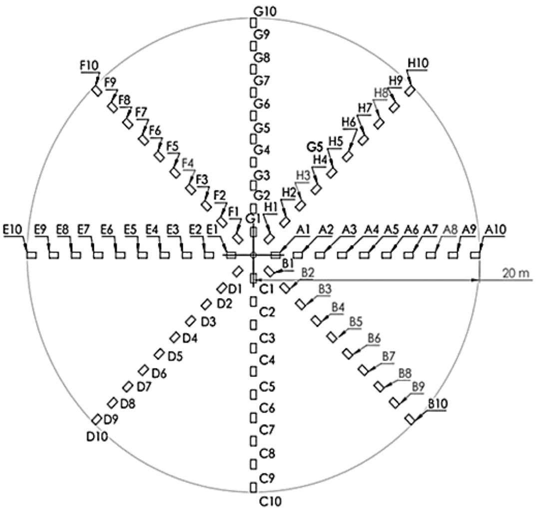


Fig. 6. Schematic diagram of the experimental collection point of the giant freshwater prawn feeder.

Fig. 7. Collecting experimental results of the giant freshwater prawn feeder.

4. Results and Discussion

The results of the distribution angle of the shrimp feeder at 0° showed that at a distance of 2 meters, the density was 0.895 mg/cm^2, and at a distance of 4 meters the density was 1.279 mg/cm^2. The density peaked at 6 meters radially away from the feeder with a maximum density of 1.787 mg/cm^2. Density decreased to 1.635 mg/cm^2 at 8 meters away from the feeder. At 10 meters the density was 1.530 mg/cm^2, at 12 meters the density was 1.333 mg/cm^2, and at 14 meters the density was 0.327 mg/cm^2. No shrimp food was detected beyond 16 meters of radial position. Shrimp food accumulation peaked at a location 6 meters away from the feeder with a density of 1.787 mg/cm^2 as shown in Fig. 8.

Due to the projectile model, the distribution angles have a significant impact on the radial location of peak density. When the distribution angle was adjusted to 100 the peak density location shifted from 6 meters further to 12 meters, while the maximum density increased from 1.787 mg/cm^2 to 2.365 mg/cm^2. An increase in distribution angles from 100 to 200 does not change the peak density location and slightly reduces maximum density. The radial location of peak density shifted to 14 meters when the distribution angle increased to 30° but the maximum density decreased to 2.19 mg/cm^2. As the distribution angle increased further to 40° the peak density location stayed the same, but the maximum density decreased to 1.804

mg/cm^2. It is also interesting to note that after the peak density location, density decreases dramatically to as low as 0.223 mg/cm^2 at 16 meters.

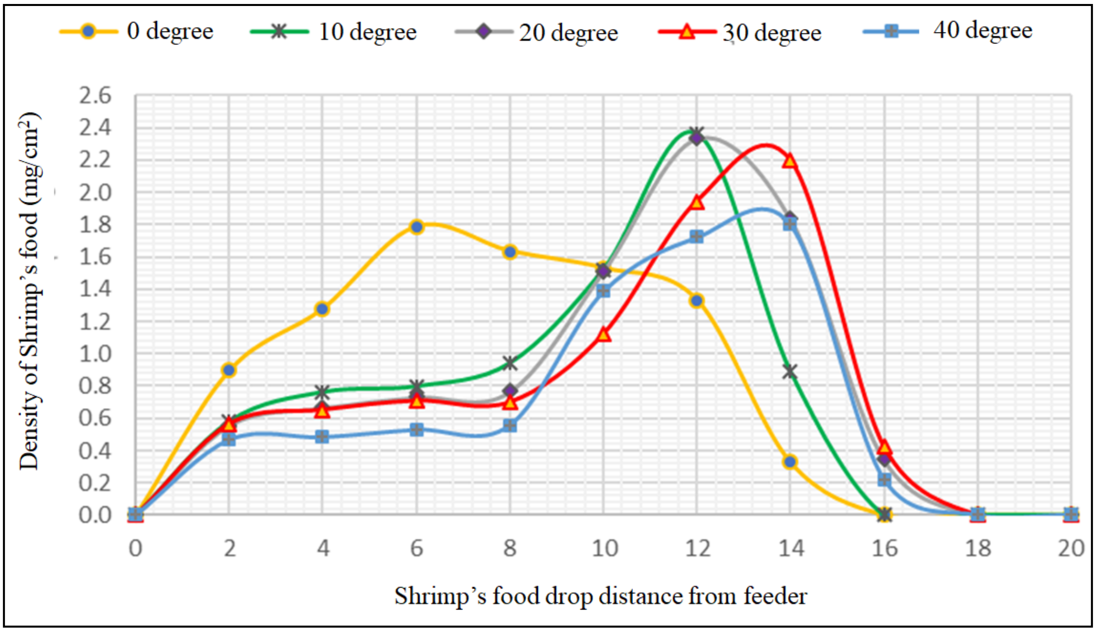


Fig. 8. Influence of distribution angle and shrimp's food drop distance on the density of shrimp's food.

The performance of the prototype was compared in terms of the coefficient of variation and uniformity coefficient. According to Fig. 9, the coefficient of variation (CV) of the feeder at different distribution angles varied slightly and ranged between 55.8% to 67.5%. CV generally demonstrated the variability of the data point which suggested the value of standard deviation relative to the mean. For this reason, a high value of CV indicated that the size of the standard deviation is very high relative to the mean of the measured density. On the other hand, the uniformity coefficient of the data point decreased gradually as the distribution angle increased to 40°. UC decreased from 52.6% to 38.0% as the distribution angle increased from 0° to 40° as shown in Fig. 10.

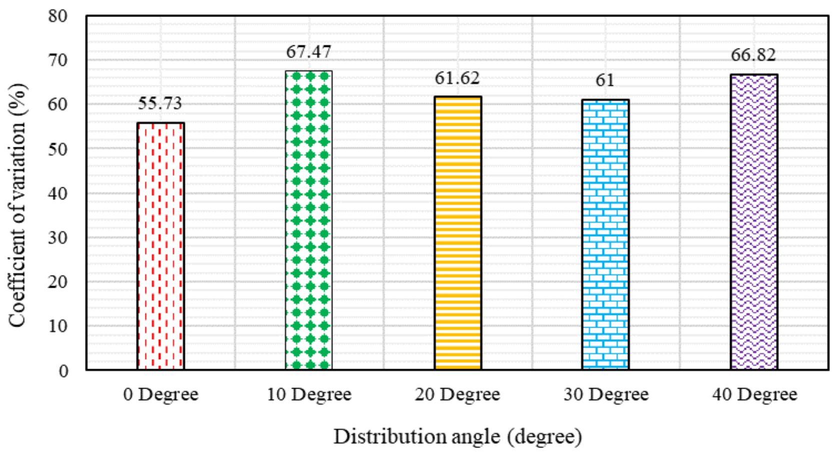


Fig. 9. Relationship between the coefficient of variation and distribution angle.

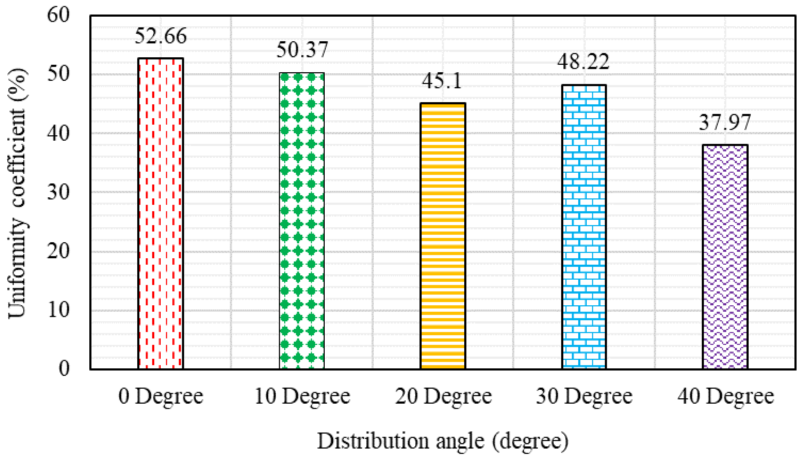


Fig. 10. Relationship between uniformity coefficient and distribution angle.

The performance of the feeder was also calculated based on theoretical data compared with experimental data at different distribution angles. An increase in distribution angle was shown to reduce the performance of the feeder in Fig. 11. Performance of the feeder when compared with the theoretical value reduced from 116.7% to as low as 31.4% when the distribution angle increases from 0° to 40°. A longer distance on average can be achieved by increasing the distribution angle, but the drawback of this is a reduction in the uniformity coefficient of the projectile drop and lower performance of the feeder. This is due to two main mechanisms: the mechanical loss from friction at a higher distribution angle and wind resistance acting on the distributed food at a higher angle [14, 15]. These two factors can be improved by adjusting the dynamic mechanism of linkage in the structure of the feeder and an improved motor with a more reliable work input [16]. The performance of the feeder as a function of the distribution angle can be calculated using the polynomial equation below with 0.9954 R^2.

$$y = -4.6417x^3 + 53.198x^2 - 196.62x + 264.13. \quad (4.1)$$

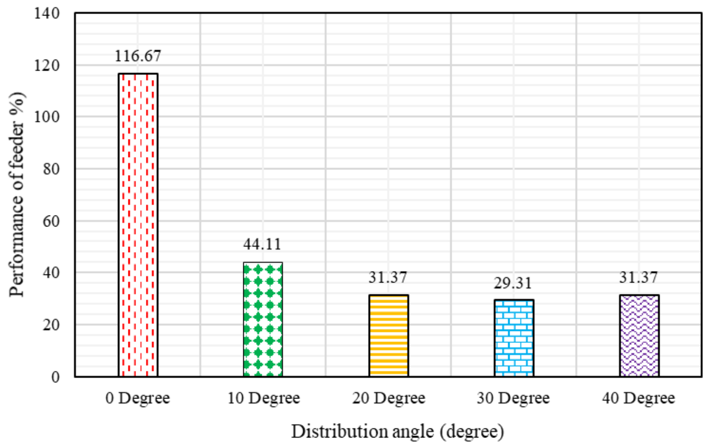


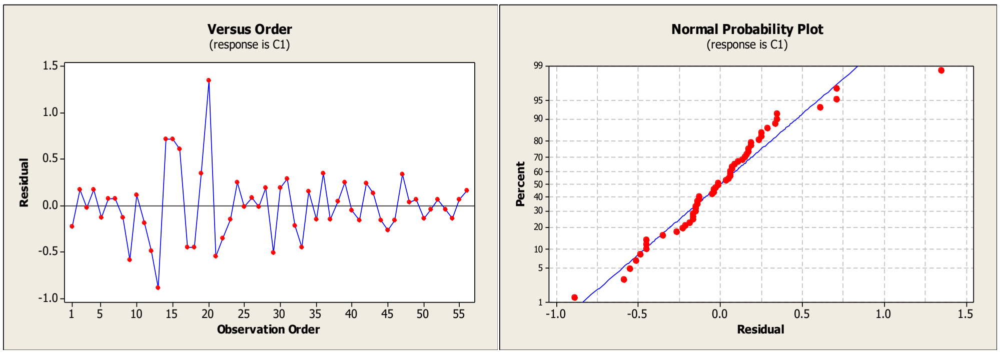
Fig. 11. Influence of distribution degree on the performance of the feeder.

Table 1. ANOVA analysis of different distance levels and distribution angles from the feeder.

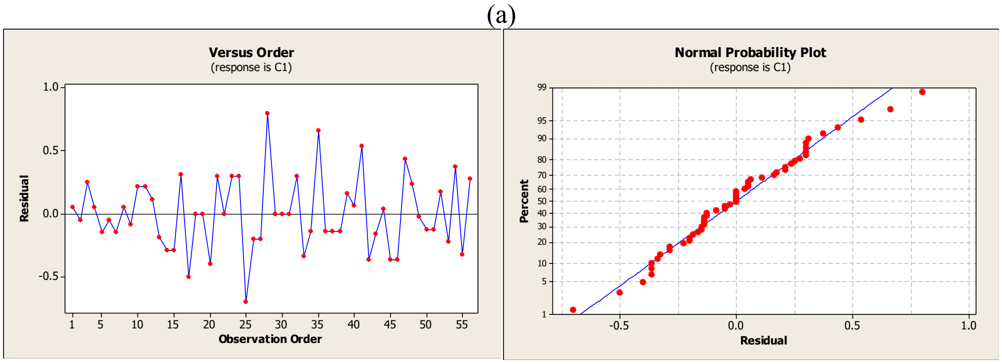
	Distribution Angle (º)				
Distance level	**0**	**10**	**20**	**30**	**40**
1	0.634	0.635	0.845	0.783	0.645
2	0.745	0.683	0.598	0.583	0.842
3	0.624	0.784	0.831	0.583	0.753
4	0.863	0.635	0.596	0.532	0.648
5	0.843	0.823	0.613	0.674	0.653
6	0.648	0.625	0.684	0.735	0.534
7	0.584	0.683	0.785	0.845	0.647
8	0.593	0.863	0.658	0.535	0.635

The expense of the feeding process is usually the most significant part of the operating cost. Additionally, overfeeding can result in devastating water quality, poor growth conditions, and more expensive electricity costs due to higher load during distribution. For this reason, it is up to the experiences of operators to control the distribution of food at the appropriate time and quantity.

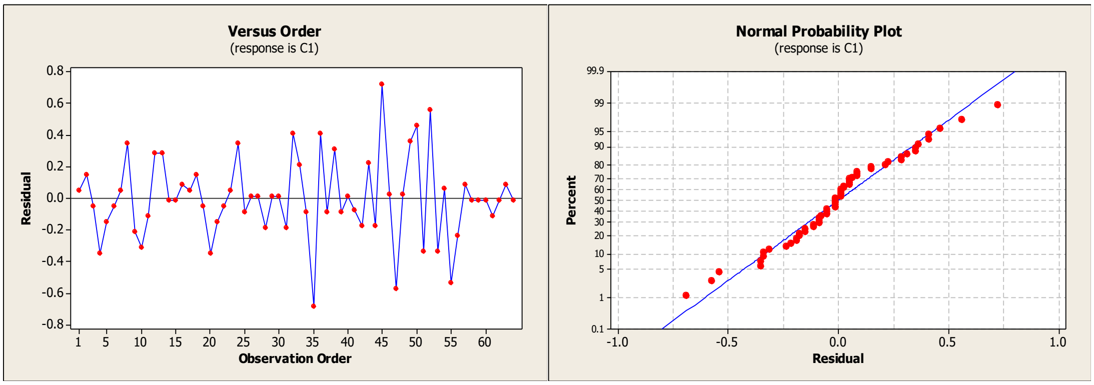
A one-way ANOVA was also used to confirm the uniformity of each distance (7-8 levels depending on the distribution angle) from the feeder distributed at different angles (0-40º). For this experiment, each data point was collected three times and then the mean of the three trials was used in the ANOVA to be analyzed at a confidence level of 95%. The ANOVA analysis demonstrated a p-value of lower than 0.05 which means that the data point collected in each level and each angle are very close together. This indicates high uniformity at each distance away from the feeder. A normal probability plot and residual plot were also developed from the ANOVA analysis as shown in Figs. 12a-12d. The two plots indicated the data points at each level do not differ significantly which means that the feeder can distribute the food at a precise distance in all radial directions.



(a)



(b)



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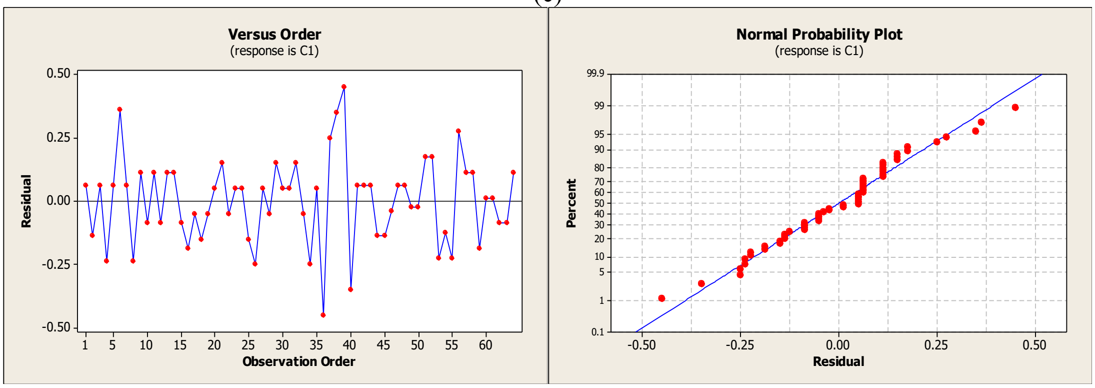
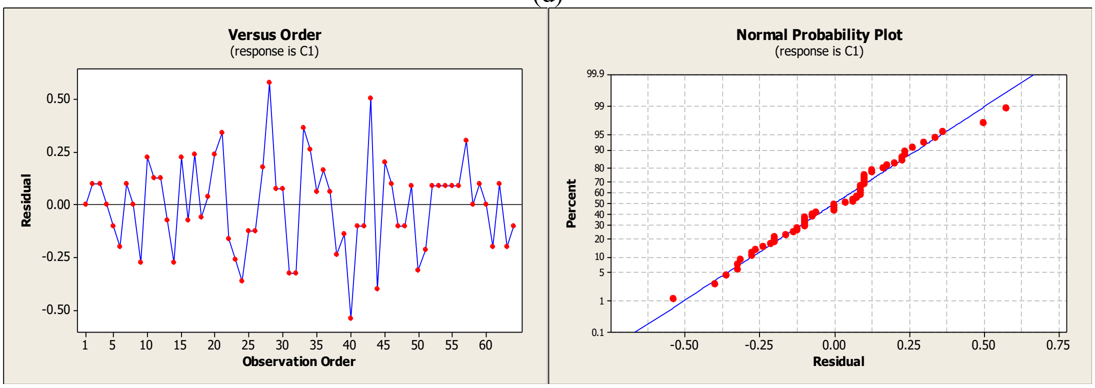


(d)



(e)

Fig. 12. Demonstrate normality probability ploy and residual plot at a) 0º angle, b) 10º angle, c) 20º angle, d) 30º angle e) 40º angle.

The capital cost of building the prototype lobster feeder is 60,000 baht and the electrical system is 20,000 baht. The minimum wage for workers in the area is 320 baht per day, therefore the labor costs added up to 9,600 baht per month per person and the energy consumption is 90 baht per month. Dividing the cost of building and installing by the monthly wage rate will show that there will be a payback period of 8.26 months or about 9 months, which is a short payback period. Data collected are similar to an experiment conducted on an acoustic optical sensing feeder system which demonstrates inexpensive components, and reduces operator responsibility and cost. Nevertheless, this type of system requires the distribution process to be connected to the food nutrients. Although automatic and on-demand feeders can help lower costs and labor expenses, it decreases hand-feeding jobs in the local area. Shrimps are among aquatic life that are simple to grow due to their reproductive potential. The main finding from this section is that the distribution angle of 30° provided the most uniform long-range trajectory of shrimp food. Estimation of operation and capital costs showed a low payback period which can attract local investors and the feeder can also be applied to many different types of ponds.

5. Conclusion

This research aims to investigate the impact of design characteristics such as distribution angle on machine operation output such as peak density location, maximum density, coefficient of variation, uniformity coefficient, and performance based on the theoretical value of the feeder system. After the implementation of the feeder on the ground, it was found that the distribution angle has a significant impact on the performance. An increase in distribution angle caused the peak density location to shift in length radially due to higher projectile motion from 6 meters to 14 meters. The maximum density of shrimp food landed on the paper sheet peaked when the distribution angle was 10°, but then reduced significantly as the distribution angle increased to 40°. The maximum coefficient of variation and uniformity coefficient reaches as high as 67.5% and 52.6% at a low distribution angle. ANOVA analysis revealed uniformity among data collected at different distance levels and distribution angles. The fixed construction cost and labor cost were 60,000 baht and 20,000. The investment payback period is 8 months after the initial operation. Results from this experiment confirmed that the prototype feeder can be used appropriately to improve the growth of shrimp in farms and can be upscaled to the shrimp industry in the future.

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