Powder Technology 263 (2014) 104–111

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Online acoustic chemometric monitoring of fish feed pellet velocity in a pneumatic conveying system

Maths Halstensen [a,*], Felicia Nkem Ihunegbo [a], Chandana Ratnayake [b], Karl Sveinsvold [c]

[a] Applied Chemometrics Research Group (ACRG), Telemark University College, Kjølnes Ring 56, N-3918 Porsgrunn, Norway
[b] Tel-Tek, Kjølnes ring 30, N-3918 Porsgrunn, Norway
[c] Skretting ARC, Stavanger, Norway

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form 14 April 2014
Accepted 5 May 2014
Available online 14 May 2014

Keywords:
Acoustic chemometrics
Partial least squares regression (PLS-R)
Process analytical technology (PAT)
Fish feed pellets
Pneumatic conveying
Optimization

ABSTRACT

Fish farmers consider the cost of fish feed pellets as one of the most expensive factors in fish cultivation. Proper control of the handling and conveying systems is necessary to avoid damage and disintegration of the cylindrically shaped fish feed pellets. Pneumatic conveying is widely used to transport large quantities of fish feed. Proneness of crushing the fish feed pellets caused by pellets interaction with the inner wall of the pipeline is a major concern to the manufacturer due to the associated economic loss; pellet damage increases exponentially with the conveying air velocity. On the other hand, too low conveying rates would lead to pipeline blockages and severe pipe vibration. In order to address the foregoing issues, it is necessary to optimize the conveying velocity of fish feed pellets during pneumatic transport. Application of an on-line monitoring technique based on non-invasive passive acoustic measurements and multivariate regression modeling (acoustic chemometrics) was investigated. A partial least squares regression (PLS-R) model was calibrated to predict pellet velocity from 19 m/s to 36 m/s in a pilot scale pneumatic conveying system. The PLS-R prediction model was validated based on independent experimental data (test set validation). The root mean square error of prediction (RMSEP), slope and r^2 of the prediction results were 0.64 m/s, 1.02 and 0.97 respectively. The prediction results obtained shows the applicability of acoustic chemometrics for real-time prediction of the velocities of fish feed pellets during pneumatic conveying.

1. Introduction

Global demand for fish products continues to increase. In order to meet this requirement, fish products come not only from wild catches but increasingly rather from land-based and off-shore fish farms. This is due to the fact that wild fisheries, which was the traditional source of fish is rapidly being exhausted all over the world therefore, prompting the need for aquaculture [1]. Fish farms however, often produce adverse environmental impacts, primarily due to unconsumed feed pellets that settle on the seabed and as a consequence excess nutrient and organic matter is accumulating [2]. There are some studies on the effect of this overloading of the seabed with organic matter as reported by Hellou et al. and Bongiorni et al. [3,4]. Many environmental and health advocates worry about the environmental pollution from marine farms especially for large species like salmon, cod and tuna. In order to reduce the pollution problem, farmed fish must be fed optimally, and precisely with the adequate amount, type and quality of feed pellets to reduce and as much as possible eliminate this unconsumed fraction.

Fish feed pellets are cylindrical and farmed fish are sensitive to the pellet shape and easily reject non-cylindrical shaped feed. Inconsistent pellets shape result in several problems including that farmer refuse to buy fish feed that do not meet up to the required specification and which thus lead to deposition of unwanted waste - and unconsumed feed on the sea bed below the farm cages. The manufacturers of fish feed on the other hand incur an economic loss due to rejection of their products.

Pneumatic conveying is widely used for handling of feed pellets in the fish feed industries, especially during loading and unloading operations on feed carrier ships and in cage feeding at fish farms. Even though pneumatic conveying is considered as a flexible, environmental friendly, hygienic transport method for biologically sensitive products, sub-optimized conveying operations may contribute significantly to pellets degradation [5,6]. The most important reason is due to pellets impacting the inner pipe wall in the conveying system and likewise collision between pellets. The phenomenon on attrition and impact damage to different particulate materials has been studied extensively by many researchers [7–10]. A common observation is

* Corresponding author. Tel.: +47 35 57 51 87; fax: +47 35 57 50 01.
E-mail addresses: maths.halstensen@hit.no (M. Halstensen), nkem99077@yahoo.com (F.N. Ihunegbo), chandana.ratnayake@tel-tek.no (C. Ratnayake), karl.sveinsvoll@skretting.com (K. Sveinsvold).

http://dx.doi.org/10.1016/j.powtec.2014.05.007
0032-5910/

that the product damage increases exponentially as a function of the conveying air velocity where also the angle of impact has a significant influence on the product damage. On the other hand, if the conveying system is operated with a too low conveying velocity, it will be subjected to inconsistent operation due to solids deposition, or become completely inoperable because of pipeline blocking [11–13]. In general, the minimum conveying velocity can be defined as the safe air velocity for consistent transportation of pellets [14]. If the air velocity is measured at the beginning (feeding point) of the pneumatic conveying system, the air velocity further downstream will be higher caused by compressibility effects, i.e. the density decrease. The air volume flow rate downstream of the flow transmitter will be higher than the measured value if the pipeline has a constant pipe diameter.

Extensive research on pneumatic conveying technology has been carried out by Tel-Tek, Dept. POSTEC, which has developed a piecewise scaling up technique [15,16], consisting of a computer software combined with an experimental procedure [17] to design and simulate industrial scale pneumatic conveying systems. The method can be applied to ensure optimized operation, addressing reliable operation, energy consumption and other common conveying problems like product degradation and pipeline erosion. In order to apply this technique effectively in pneumatic conveying of fish feeding, it is important to have access to a reliable real-time monitoring method for conveying velocity.

In recent years, several on-line techniques commonly referred to as Process Analytical Technologies (PAT) have been implemented in numerous areas of science and technology for research and development and industrial process characterization. PAT was primarily intended for on-line applications in the pharmaceutical industries [18] but has since been developed for numerous other purposes and has evolved over the years and is presently dominating the field of industrial monitoring [19]. On-line monitoring techniques have been attracting many research efforts during the past years. Driven by the increasing maturity and adoption, PAT methodologies have played an important role in the optimization of industrial processes and products. Increased interest from the industry has also led to development of a new range of sensor technologies. The most desirable sensor probes are the non-invasive type which does not disturb the process and are easily mounted without any modification of the process equipment. The cost and reliability of these methods also influence on their merit and benefit.

Acoustic measurement approaches have previously been applied in powder science to characterize pneumatic flow [20]. Acoustic chemometrics is a non-invasive on-line PAT technique which has entered a new phase in recent years. The recent advances offer vast opportunities for research and development in areas of technological applications which are documented in the literature [21–25]. Mass flow rates of material transported in pneumatic conveying lines in dilute phase [21] and dense phase [26] systems have previously been investigated. Acoustic chemometrics was previously applied by Huang et al. [27] for monitoring of powder breakage during pneumatic conveying. However, literature on determination of velocity of material during transport by means of acoustic measurement and multivariate data analysis does not exist. On-line prediction monitoring of the pellet velocity gives valuable information for the process operators for optimal process operation with respect to product degradation. Another advantage is that energy consumption can also be optimized as described by Ratnayake [18].

The experiments reported here were primarily designated to improve the performance of a pellet feeder and conveying rig in a bulk carrier ship used by a fish feed manufacturer. The main objective was to improve the quality of fish feed product delivered to the customers. Material feeding from a discharge tank to a conveying pipeline was arranged through a full scale feeding valve. The main focus was to investigate how acoustic measurements and multivariate data analysis can be used to predict the pellet conveying velocity.

The tests were conducted using a pneumatic test facility in the powder research laboratory of Tel-Tek, POSTEC, Norway. The experiments were designed to include pneumatic conveying of fish feed pellets with different conveying velocities (by applying different air flow rates), under collective behavior. The acoustic chemometric approach involved recording of acoustic signals of pellets impacting the conveying pipeline during transport. Partial Least Squares Regression (PLS-R) was used for model calibration.

2. Materials and methods

The pilot scale conveying rig was designed and operated to simulate a full-scale transport facility in a bulk carrier ship used to transport fish feed pellets from the manufacturing plant to the fish farms. The conveying rig consists of several large silos with a capacity of approximately 60 tons, and pipelines with different diameters (125 mm, 150 mm and 200 mm).

2.1. The pneumatic conveying rig

The pilot scale pneumatic test rig was used to transport feed pellets under different process conditions. The major components of the test rig have been made by scaling down the corresponding pipe elements of a full scale feed pellets conveying rig [28]. Fig. 1 shows a schematic overview of the test rig.

The test rig consists of a discharge tank of 2.5 m^3 capacity, a receiving tank, and a 40 meter long pipeline with an internal diameter of 75 mm. On the horizontal section of the pipe just below the feeding tank (see Fig. 1) a transparent pipe section was inserted to allow high speed video capture of the fish feed pellets during transport. Feeding of the material from the discharge tank to the conveying pipeline was arranged through a full scale feeding valve provided a major manufacturer. The conveying line forms a closed loop circuit with the receiving tank on top of the blow tank. The advantage of this arrangement is that the pellets in the receiving tank can be filled into the blow tank and thus make the material ready for the next experiment without removing it from the test rig.

The air supply was provided by a combined screw type air compressor and drier. The pressure and volume flow rate of supply air were controlled by a controller valve.

Traditional process measurement transmitters such as pressure, flow, temperature and humidity meters were also mounted on the transport line in order to monitor and operate the test rig properly. The rig was equipped with facilities for continuous logging of air pressure at various locations, air temperature, humidity, material transport rate etc, on a real time basis. The data acquisition and analyses were undertaken with LabVIEW® software.

The reference velocities required for calibration and validation of the PLS-R models were obtained from visual inspection of high speed video recordings of the material as it passed through the transparent section of the pneumatic transport line. The high speed video was recorded simultaneously as the acoustic spectra were acquired.

Acoustic signals were acquired from four accelerometers mounted on the test rig in four different locations on the pipeline (see Fig. 1). Sensors 1 and 2 which were mounted 90° to each other and the same was done for the other sensor pair (sensor 3 and 4).

2.2. The test material

The type of fish feed used in all the experiments was Optiline 2500 which was provided by a major producer. The fresh pellets were of cylindrical shape with 10 mm length and a diameter of 9 mm. The bulk density of the pellets measured under loose poured and tapped conditions was in the range of 670-720 kg/m^3. Fig. 2 shows a collection of fish feed pellets with a scale attached for clarity.