Industrial Crops & Products 123 (2018) 128–134

Contents lists available at ScienceDirect

Industrial Crops & Products

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

An extractor for unloading the wet biomass stored in silo-bag

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ARTICLE INFO

Keywords:
Storage
Unloading machine
Corn silage
Biomass
Bioenergy
Biogas

ABSTRACT

The storage of wet biomass can produce some problems when the biomass is emptied from silo-bags. Its extreme compactness and adhesion to the extractor cause clogging and product loss. Despite the importance of such an operation, the problem of silo-bag emptying has been addressed only rarely. This paper describes a new prototype of extractor designed for unloading the wet biomass from silo-bags. The machine was tested on silo-bags (of a capacity of around 200 t) filled with corn silage stored for two months. The study analyzed the qualitative parameters of the feedstock (density, moisture content, and particle size distribution), and the performance of the extractor in working conditions at three forward speeds (14.4, 18.0, and 21.6 $m\,h^{-1}$). The extraction capacity of the machine proved comparable at the three speeds, but the maximum value (38.5 $kg\,cm^{-1}$) was achieved at 18.0 $m\,h^{-1}$. This speed, however, resulted in some clogging problems which caused a reduction in the working time (23.5%). Overall, the productivity proved satisfactory, ranging from 50.5 (at a forward speed of 14.4 $m\,h^{-1}$) to 82.6 $t\,h^{-1}$ (at a forward speed of 21.6 $m\,h^{-1}$), while the material losses caused by the mechanical action of the extractor were low (0.09% w/w).

1. Introduction

The use of silo-bags to store dry grains and wet biomass to be used for food, animal feed, and bioenergy production was first introduced in the early 1990s in Argentina, later spreading to more than 40 countries worldwide (Barreto et al., 2013; Darby and Caddick, 2007). Argentina is currently the world leader in this technology (Casini et al., 2009), but a widespread use of silo-bags has also been reported in the USA (Muck and Holmes, 2006; Subramanyam et al., 2012), Canada (Jayas et al., 2011), and Australia (Darby and Caddick, 2007), while in other countries such as Italy the system is in the initial study stage (Pezzuolo et al., 2016). Silo-bag storage can be considered an on-farm "buffer" management option (Darby and Caddick, 2007) with some advantages. The hermetic sealing ensured by the plastic bag protects the biomass from water, while the airtightness of silo-bags makes it possible for the CO_2 produced by the respiration of biotic components (correspondingly consuming O_2) to be kept inside, thus contributing to controlling the insect population (Barreto et al., 2013; Busato et al., 2011; Chelladurai et al., 2016; Darby and Caddick, 2007). The silobag proved to be easy to manage because it does not require fixed cost structures and can be a prompt solution for temporary surplus, while at the same time increasing the harvest window of high-moisture biomass (Darby and Caddick, 2007).

This technique has mainly been applied to grain silage and has been used for corn, wheat, barley, canola, soybean, and sunflower (Bartosik, 2012; Ochandio et al., 2010), but its use can be extended to energy crops (Corno et al., 2016). To some extent, the idea of using it for energy crops has given new impetus to the sector and led to new ideas for additional improvements. Over the past ten years, in fact, the growing demand for vegetable oils as a renewable energy source (biodiesel) has increased the import of soybean, canola, sunflower, and palm into the European Union (Ochandio et al., 2010). The estimation of the biomass required for energy use in 2020 is 136 million tons (Lewandowski, 2016), leading to a growing demand for more storage capacity. Such a trend requires the set-up of storage solutions which are economically sustainable, efficient, and able to ensure the quality of silage and lower dry matter losses.

In Italy, the increased biogas production has been fast enough in recent years to make it the second European country in number of plants (Carrosio, 2013), most of which are mainly fed with corn and other grain silage stored wet (Dinuccio et al., 2010). As shown by Pezzuolo et al. (2016), the storage of corn for anaerobic digestion could benefit from the adoption of the silo-bag system, which makes it possible to reduce costs by 7% and energy use by 8%. The environmental impact of corn ensilage proved to be lower (from –5% to –9%) when the silo-bag was used instead of the bunker silo, a difference mainly due to a lower loss of dry matter (Bacenetti and Fusi, 2015). New insights are becoming available concerning the ensilage of other interesting energy crops which are suitable for anaerobic digestion, such as giant reed (*Arundo donax* L.) (Liu et al., 2016), while other studies have

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https://doi.org/10.1016/j.indcrop.2018.06.051
Received 29 January 2018; Received in revised form 8 June 2018; Accepted 12 June 2018

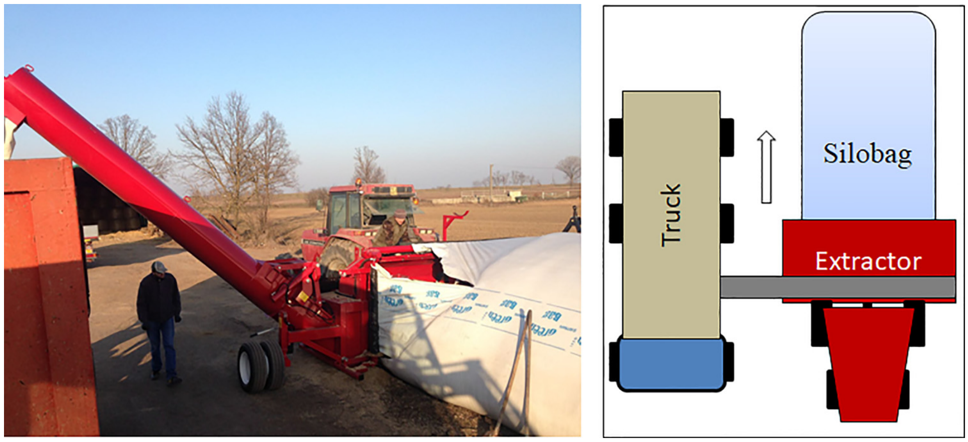

Fig. 1. View of the extractor during the unloading (left) and scheme of the configuration at work (right).

demonstrated the efficiency of silo-bag storage in preserving the biogas potential of *Arundo* better than the traditional bunker silo (Corno et al., 2016).

From a logistical standpoint, silo-bags are filled by bagging machines, either tractor-mounted or –trailed or self-propelled. A hopper or an auger (frontal or lateral) loads the feedstock directly from a truck or trailer. The feedstock is discharged into the silo-bag by a system of augers or by gravity. A bagging machine supports and holds the bag while it is gradually unrolled as it is filled.

The bag extends and expands due to the pressure exerted on its walls from the inside. The forward speed of the bagging machine is regulated by the filling rate. After reaching the desired filling length, the bag is hermetically heat-sealed. The unloading of horizontal silos is more complex because of the sticking of the material to the bag, thus reducing the efficiency of the machine and increasing the loss of material. Specific tractor-towed unloading machines are widely used where the horizontal system is the one most commonly employed (Bartosik et al., 2013; Busato et al., 2011). In short, they are equipped with elements, often augers, which are able to enter the bag and convey the product toward a certain point, from where a system integrated with the extractor machine loads the feedstock onto towels or trucks. In the case of non-granulated silage, the unloading system may include differently shaped grinding elements (e.g. blades, knives, hammers) which perform the task of disrupting and disaggregating the compacted wet matter.

In Italy, silo bags are used mainly for storing grain, but their extension to wet biomass for livestock or energy production may be of great interest in the bioenergy sector. However, a major problem to be solved is the lack of an efficient unloading system for wet biomass. The available machines are designed for the management of dry grains or other granular products (e.g. fertilizers). Due to its physical structure, the wet biomass tends to become extremely compacted and to adhere to the machine walls. This requires complex systems to prevent the clogging of the product during unloading, thus increasing the risk of product loss and additional costs for its recovery.

Such issues have prompted some companies to explore innovative solutions to obtain a more efficient recovery of the wet biomass. The objectives of the present study were: i) to describe the development of a new prototype of extractor designed for the unloading of wet biomass, ii) to analyze the results of its first functional trial in working conditions, iii) to provide some suggestions on the mechanical emptying of the silo-bag, a key phase often overlooked.

2. Materials and methods

2.1. The site

The development of the prototype took more than two years, during which successive versions of extractor machines were tested in different conditions and on different storage sites.

These first unloading tests on a prototype set-up using sorghum and corn fibers cut at different lengths – whose results are not presented in this paper – were conducted in northern Italy (Emilia-Romagna and Lombardy regions), near biogas plants which are characterized by a high consumption of biomass crops. The performance test on the final version was carried out in Villanova di Ravenna (44°22′44″ lat. N, 12°6′56″ long. E – Ravenna, Italy) at the headquarters of the Boschi Servizi Company in September 2015.

2.2. The prototype

The prototype described in the work was equipped with a system able to crumble and convey the feedstock onto a ground pile or trailer/truck, and with a device for the recovery of the empty bag. The main components of the original design were:

- a frontal reel shredder, consisting of four grinding devices positioned in front. The task of this component was to disaggregate the compacted biomass;
- a horizontal auger parallel to the reel, for the collection of the biomass disaggregated by the reel;
- a second adjustable oblique auger for the lateral discharge of the product;
- a rear roller for the recovery of the silo-bag's plastic film.

After the first experimental tests the machine was modified because, despite the feed system being faultless, the grinders showed some functional limitations in conveying the biomass. Consequently, the grinders were modified. In the last version, a basal auger has been integrated with an upper rotary hammer to improve the shredding action on the biomass profile. The main intervention in the third version (Fig. 1) consisted of replacing the basal grinder with a central auger able to ensure a smoother conveyance. This made it necessary to modify the oblique auger as well. Further simplifications were introduced in the last version. A main basal auger conveyed the product laterally while, in the upper position, there was a frontal grinding system with separate elements.

Once disaggregated, the biomass was collected by the basal auger which conveyed it to a second auger. The latter had a smaller diameter and was equipped with adjustable hydraulic arms. Its function was to