Review of Literature on Steam Accumulator Sizing in Palm Oil Mill

Mohd.Halim Shah. I

Department of Chemical & Environmental Engineering, Faculty of Engineering
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
E-mail: mshalim@eng.upm.edu.my
Tel: 603-86466287; Fax: 603-86567099

Mustafa Kamal A. A

Centre of Lipids Engineering & Applied Research (CLEAR)
Universiti Teknologi Malaysia 54100 Jalan Semarak, Kuala Lumpur, Malaysia
E-mail: clear_utm@yahoo.com
Tel: 603-26154880; Fax: 603-26935466

Noor Azian M

Centre of Lipids Engineering & Applied Research (CLEAR)
Universiti Teknologi Malaysia 54100 Jalan Semarak, Kuala Lumpur, Malaysia
E-mail: clear_utm@yahoo.com
Tel: 603-26154880; Fax: 603-26935466

Abstract

Previous work in the area of improving the performance of steam system in palm oil mills can be found in books and journals published by Malaysian Palm Oil Board (MPOB). However, very little data has been published on operating experiences and scientific facts as well as economic aspects of back pressure vessel system. The data is also often found to be contradictory with the actual industrial requirement in handling pressure fluctuation of steam line in palm oil mill. Furthermore, there is very scarce literature on proper sizing methods for back pressure vessel. The design of back pressure vessel in palm oil mills is still largely based on undeveloped approaches and is carried out by individuals lacking exposure to the palm oil milling industry. The size of back pressure vessel varies between 1 to 12 m^3 and the choice is usually dictated by the manufacturer and the capacity of steam consumed by turbine. But, this size is always found to be insufficient to control the steam distribution to sterilisers and other heating processes.

Keywords: Palm oil mill; Steam accumulator; Steam pressure; Specific steam storage capacity; Sterilisers

1. Previous Studies on Steam System in Palm Oil Mills

One of the pioneering works on the fuel and steam balances in palm oil mills is credited to Sivasothy et al., (1989 & 1998) concluded that about one-third of the total steam generated is consumed by the steriliser. The batch nature of sterilisation process has made the whole energy system in palm oil mills

more difficult to achieve good steam management. This batch operation causes fluctuations not only in the materials (FFB and crude palm oil) being processed, but also in the process steam demand. The use of high pressure steam and intermittent pressure exhaust steam to achieve good sterilisation in current mill practice was reported to have complicated the mill to achieve continuous milling condition. Mustafa (1990) have reported that the non-integration of steam system units and differing process control were the ultimate reasons that led to the extreme steam fluctuations in palm oil mills. Consequently, there are several levels of response or effect from the disturbances.

The fastest and most apparent level is pressure drop in the boiler or on the contrary the build-up of steam in the boiler, causing the degradation of power from the steam pressure. There were cases of steam surplus being too high that the performance of steam turbine was severely affected. This is usually encountered by venting off the steam from the back pressure vessel. The next level and slower response is the depression in the steriliser pressure. Therefore, peak performance of sterilisation process could not be attained consistently, resulting in hard fruits, unstripped bunches and lower extraction rate. The last and slowest response is the effect of steriliser's performances on the sterilised fruits quality and subsequently on the production of the crude oil, kernel, shell and fibre. An ambitious research project for the automation of sterilisation process was undertaken by Sivasothy et al., (1989). The project was directed towards improving the sequencing of sterilisers and minimising the fluctuations in the overall steam demand in mill. Commercial process control tools such as programmable control-based system and PC-based system (GENESIS Process Control System) with comprehensive graphical interface as well as easy configuration features were installed in palm oil mills to control the sterilisation process. The developed system was reported to have the potential to improve the conventional monitoring capability of sterilisation process.

Zainol (1990) have reported that the major problem of back pressure vessel was the loss of steam of about 27 to 50% to the atmosphere. This is due to its design and size which are not specific for accumulating and controlling the steam distribution to the sterilisers and factory heating. Its function is more as a temporarily steam storage vessel for maintaining the turbine performance. The practice of venting off steam from the back pressure vessel to atmosphere over a certain minimum time is inevitable when the accumulation of steam in the back pressure vessel exceeds the relief valve set point (around 45 psi). Consequently, there is a deficit in steam supply to the sterilisers, resulting in fresh fruit bunches not being fully sterilised. Mustafa (1994) have identified three major types of disturbances that led to the severe steam fluctuations in steam supply and demand. The most critical type is random steam fluctuations in boiler, steam turbine, back pressure and sterilisers resulting in steam venting or time delay. The next disturbance is variation of boiler pressure due to inconsistent fuel quality which affects all units downstream and the last type is random steam injection in palm oil stream such as digester to maintain temperature and flow. Ng (1994) have reported that under the best sterilisation condition with proper sequencing of the three sterilisers, there was an increase in steam input to the steam system, but the steam loss through the boiler and the back pressure vessel to the atmosphere has also increased. The back pressure vessel accounted for about 65% of the total steam loss to the atmosphere. This high steam loss is mainly due to its size limitation to control and cope with the steam demand at the sterilisers because of the enormous difference in volume between the back pressure vessel and the sterilisers.

Sivasothy (1997 & 1998) have identified that one of the problems experienced with boiler control systems was the slow dynamic response of the steam pressure to changes in fuel firing rate. This constraint tends to restrict the ability of simple feedback systems to respond to sudden large fluctuations in steam demand. As in the above case, several experimental studies were performed by implementing a feed forward control system where fuel flowrate to the boilers could be increased before the start of sterilisation cycles in anticipation of an increase in steam demand. The problem of slow dynamic response of steam pressure is significantly eliminated using the new control system. A practical and integrated approach to the steam management for palm oil mills known as the millwide intelligent steam management control system was proposed by Lim et al., (1997). This control system comprises various critical process control sub-systems such as steriliser control system, back pressure

receiver control system, combustion control system and boiler drum level and blow control systems to maintain a balance between steam demand and supply. The major sub-systems and the schematic layout of the control system are shown in Figure 1. The millwide intelligent steam management control system for palm oil mills has reported both encouraging and beneficial results. From the literature reviewed above, it can be concluded that one of the most critical problems faced by palm oil mill industry is the severe and dominating periodic fluctuations of steam supply and demand.

Therefore, a proper energy management is needed to be implemented in the steam system for providing solution to the problem.

Figure 1: The major sub-systems and schematic layout of millwide intelligent steam management control system (Nicholas Lim et al., 1997)
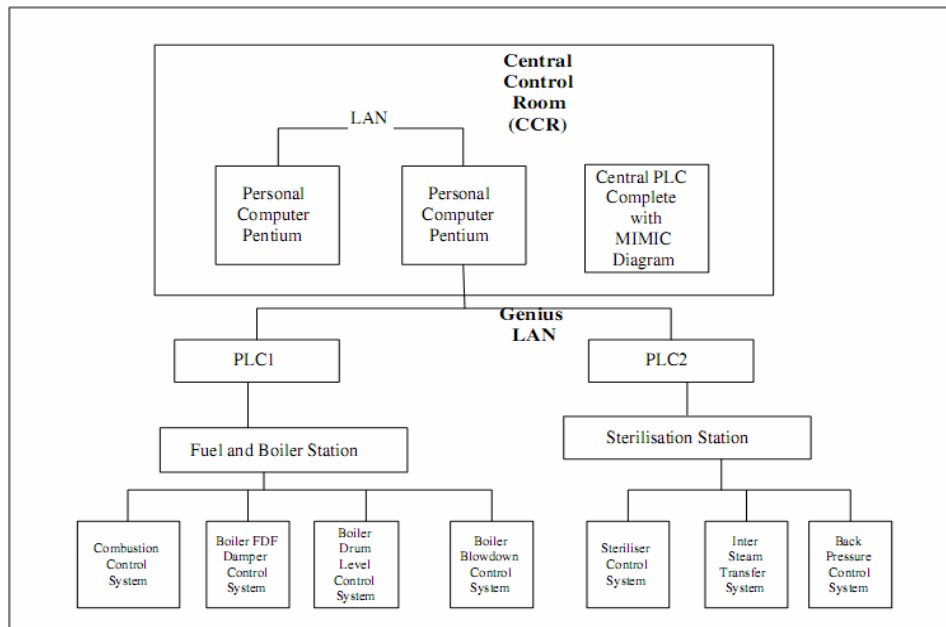
2. Development of Steam Accumulator

The first steam accumulator was installed at the beginning of this for balancing the waste steam from winding machines (Goldstern, 1970). The principle of steam accumulation used in the system was limited for the pressure range of up to 2 bars and automatic regulation was not yet incorporated. Ruths (1913) then applied the same basic principle of steam storage to higher pressure systems and automatic operations in 1920's. In connection with the new development, the application of pressure drop accumulator to balance the boiler load by inserting an overflow or surplus regulator between the boiler and the accumulator has been successfully carried out. This was followed by similar developments of the feed water storage system or constant pressure accumulator for medium fluctuations, especially the displacement type in 1960 (Godall, 1980). For power station applications, special storage systems for turbines were developed with pressures up to 150 bars in 1938 (Lyle, 1947). At present, new systems are being developed for nuclear power and for solar and other unconventional sources of energy, aiming at steam storage volumes of several thousand cubic meters per unit.

3. Industrial Application of Steam Accumulator

A steam accumulator is a pressure vessel, partially filled with hot water that allows the operation of boiler at a constant output equal to the average steam demand. To use a steam accumulator, there must be some demand on steam at a pressure significantly lower than boiler and the maximum high pressure

demand cannot exceed the boiler operating rate. The fluctuating load can be either at low pressure main or high pressure main. However, when the steam consumption of a factory or mill is fairly constant and there are no sharp peak demands, then an accumulator are not required (Price, 1982). Steam stored in a steam accumulator is immediately available to the consumers and can be used to supplement various types of steam demand. For short periods, the accumulator can discharge steam at very high rates and reduce the size of the boiler plant required.

When steam is subject to regular cycles or predictable fluctuations, the load can be balanced for hours or even days. In every case, there will be a more steady load on the boiler plant, whereby losses are reduced and fuel savings achieved. Thus, steam storage acts as an additional tool to ensure that steam supply is adequate and efficient at any time. Furthermore, it can convert the most unfavourable type of steam demand fluctuation to the most favourable type with steady consumption (Goldstern, 1970). Goldstern (1970) has reported that an adequate size of accumulator installation is capable to introduce an elastic connection between the steam generator and the user. The steam accumulator can take the acute load fluctuations. Consequently, the generation of steam from the boiler can be made uniform and held constant for long intervals. The effect of steam accumulator on balancing pressure fluctuations in the steam demand is shown in Figure 2 and Figure 3. Maycock (1984) has proposed a new layout for steam system in palm oil mills with the installation of steam accumulator as shown in Figure 4.

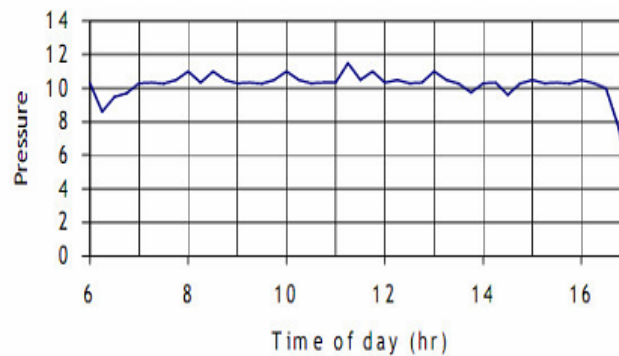**Figure 2:** Pressure variation without steam accumulator

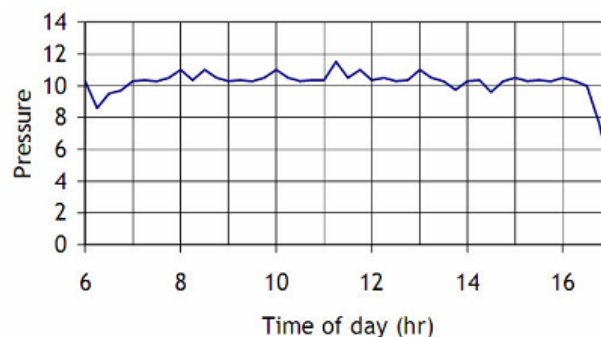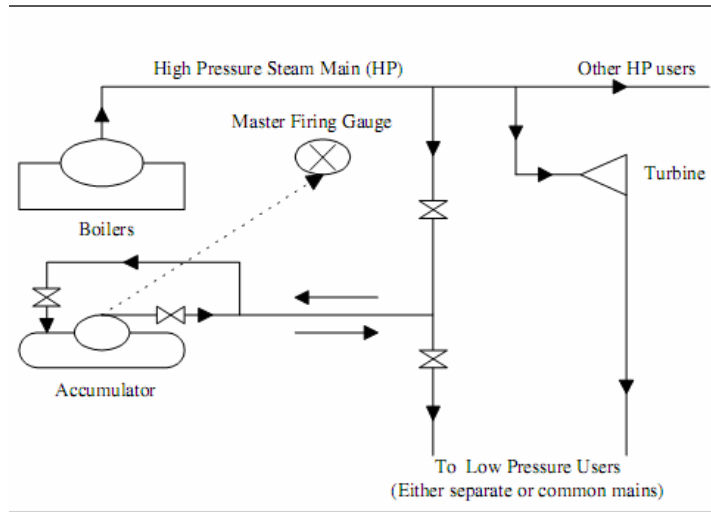**Figure 3:** Pressure variation with steam accumulator of adequate size

Figure 4: Diagrammatic layout of steam accumulator plant

With the accumulator, the boiler would be at a substantially constant or average firing rate in accordance with the dotted line 'a-a' as illustrated in the variations in steam demand chart, Figure 5. The largest single area above or below the average steam demand line 'a-a' in Figure 5 is the ideal steam storage requirement. By installing the steam accumulator, the pressure both on high and low pressure mains would be practical constant and independent on the variation of steam demand. There are, in principle, two different systems possible for the storage of thermal energy (Godall, 1980).

Figure 5: Variations in steam demand
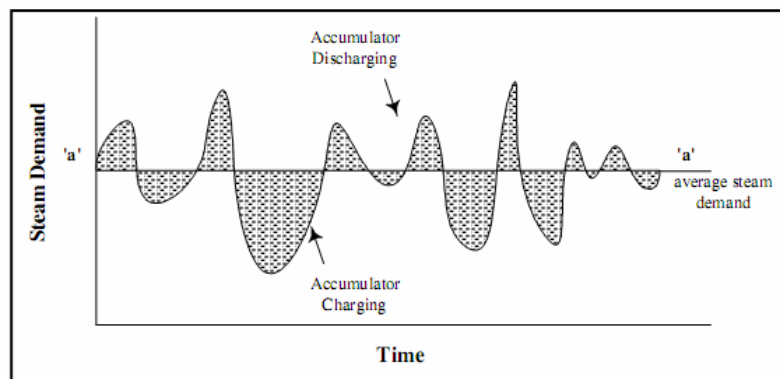
The first system is pressure drop or varying pressure accumulator, operating on the principle of a constant volume of water, while pressure and temperature are allowed to vary. This system usually arranged horizontally, consists of the pressure vessel with insulation, the necessary accessories and the charging equipment. When fully charged, it is normally about 90% full of hot water. During periods of low demand, surplus boiler steam is blown to the pressure drop accumulator, below the water level in it through the charging equipment. The steam condenses quickly, as its temperature is higher than that of the surrounding water and the water is heated. This results in increase of the water temperature and the pressure rises correspondingly until it reaches that of the incoming steam. However, during periods of high demand, steam is allowed to leave the steam space of the accumulator by opening a valve and the pressure in the accumulator drops accordingly. This causes the water, being at a higher temperature than steam in the steam space, to boil and thereby displace the discharged steam by evaporation. This process continues until the accumulator pressure reaches the low pressure of steam consumers. The

balancing effect of pressure drop steam accumulator is illustrated schematically in Figure 6. The second system is constant pressure accumulator can be called feed water accumulators, operating on the principle of a constant pressure or temperature of the water, while its volume is allowed to vary. It consists of the pressure vessel with insulation and accessories as well as charging equipment. The vessel is usually arranged in a vertical position. This allows both hot and cold water to be stored in the same vessel where the hot water in the top part and the cold water in the bottom part. The principle behind the feed water accumulator is shown in Figure 7.

During the charging operation, the surplus steam enters the steam space and mixes with cold feed water. The steam is condensed and the feed water heated to the saturation temperature corresponding to the steam pressure. As hotter feed water is produced, less cold feed water remains in the bottom part of the accumulator; thus the dividing line moves downwards, until the whole accumulator is filled with hot feed water. When discharging takes place, less feed water is preheated than is required for boiler feed, and this means that the boiler can supply a corresponding amount of additional steam to the consumers. In the event that no preheating takes place at all, the discharge rate reaches its maximum as the boiler output is increased by the whole amount of steam which is otherwise used for preheating. The accumulator will gradually come to contain less hot and colder water, until it is fully filled with cold feed water. There are two graphical methods available for determining the storage capacity of steam accumulator (Goldstern, 1970). Basically, these methods are the same in principle but only differ in the maximum allowable working pressure.

Figure 6: Balancing effect of the pressure drop accumulator
(a): Direct balancing of fluctuating low pressure demand
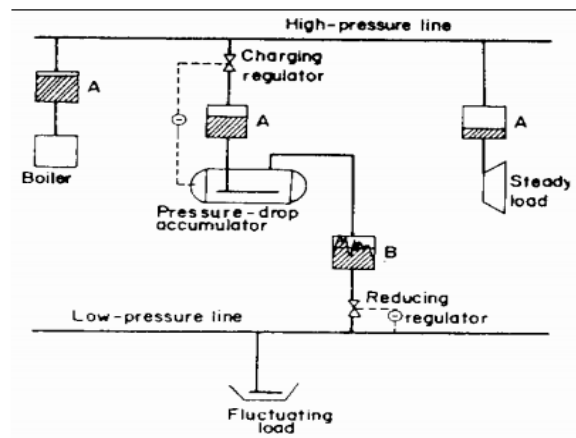
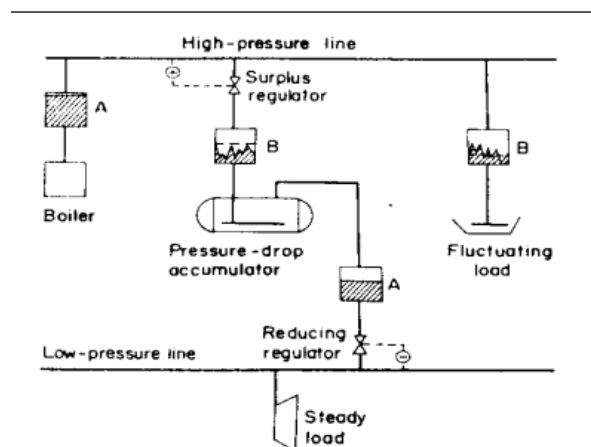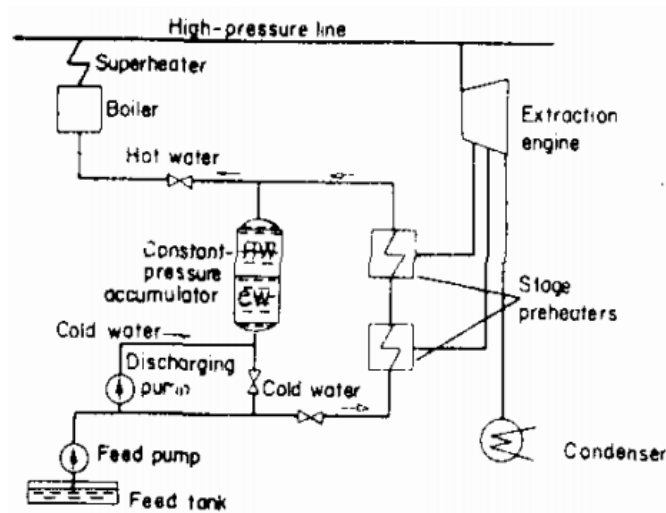**(b):** Indirect balance of fluctuating high-pressure demand. A-steady flow; B-fluctuating flow.
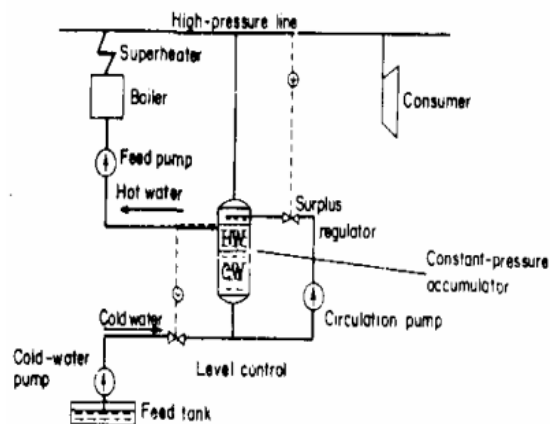
Figure 7: Arrangement of constant pressure accumulator.
(a): Preheating by steam and water mixing

(b): preheating by extraction steam.

The first method is used to determine the storage capacity of an accumulator at low pressure up to 20 bars whereas the second one is only applicable for high pressure systems up to 200 bars. The backbone of the methods is heat balance derived from the stored quantity of heat storage either in the form of steam or hot water as well as the state of accumulator either charging or discharging cycle. Therefore, for sizing an accumulator, the above two methods require the maximum and minimum accumulator operating pressures and the quantity of steam to be stored. The design of steam accumulator vessels may be either horizontal or vertical. However, the horizontal type is generally preferred due to the cheaper cost of construction. Godall (1980) has suggested the best ratio of diameter to total length of a steam accumulator should be between 1:4 and 1:6 in order to obtain optimal condition in terms of thermal storage capacity and material cost.

The basic tests of Eberle (1929) have shown that primarily the steam space and not the evaporative surface is important for the maximum permissible evaporation (Goldstern, 1970). This is due to water turbulence which always occurs during discharging cycle. The maximum permissible rate of discharge given by Eberle was 2000 m^3/hr for pure water, but only 200 m^3/hr for alkaline corresponding to 1 m^3 of steam space. Cleve (1949) and Konejung (1950) have developed a correlation which relates the maximum rate of evaporation to the storage pressure and the density of the storage water (Goldstern, 1970). Lyle (1947) has reported that the rate at which an accumulator can be allowed

to discharge is limited by the rate of water ebullition can take place at the liquid surface without the entrainment of water droplets. From the observation, the maximum permissible rate of flash per square feet of water flashing surface in the accumulator was three times the absolute pressure in the accumulator. Steam accumulator is faced with very different tasks in different industries. This is due to the design of the steam system and also the type and amplitude of the fluctuations to be balanced. These fluctuations usually are affected by the nature of the production process. In other words no two steam accumulators are comparable, since besides differing in dimensions and method of storage, the range of pressure or temperature and the arrangement within the steam plant may be different, as well as the type of operation and the purpose of the steam accumulator (Goldstern, 1970). Fluctuating loads requiring the application of steam accumulator are usually found in batch processes (Price, 1982). Some of the typical examples of steam accumulation installation in different industries are described below:

3.1. Carpet factory

A varying pressure steam accumulator of diameter 3m and length of 10m, working in the pressure range between 2 and 10 bars was installed to cope with the peaks in steam demand that occurred due to large holding dye vats when the vats were heated up. The plant layout of the steam accumulator installation in the carpet factory is illustrated in Figure 8. In addition to a substantial fuel saving, the accumulator ensures adequate steam supply, even for an additional dye vat, which would on the contrary; require the installation of an additional boiler.

Figure 8: Pressure drop accumulator for supplying peaks in carpet factory
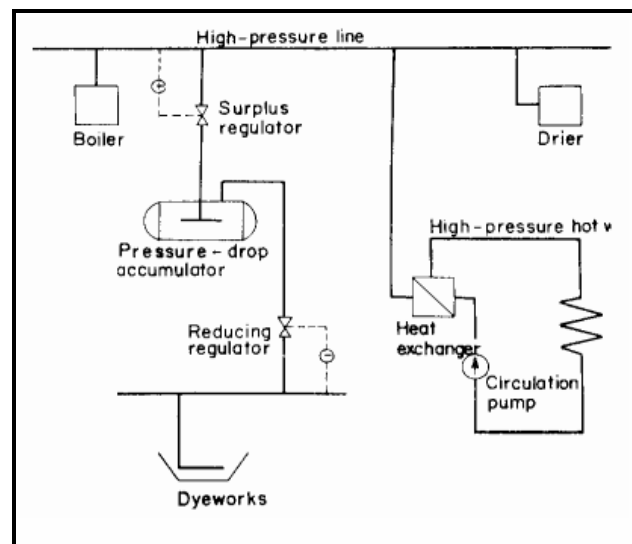
3.2. Steelworks

A constant pressure accumulator pressure with storage capacity of 4500 kg and maximum output rate of about 6 tonnes/hour was used to reduce the variation of the boiler pressure caused by the load fluctuations of the steam hammers and presses during peak periods. The layout of the constant pressure accumulator system is shown in Figure 9.

Figure 9: Constant pressure accumulator for balancing load at steelworks
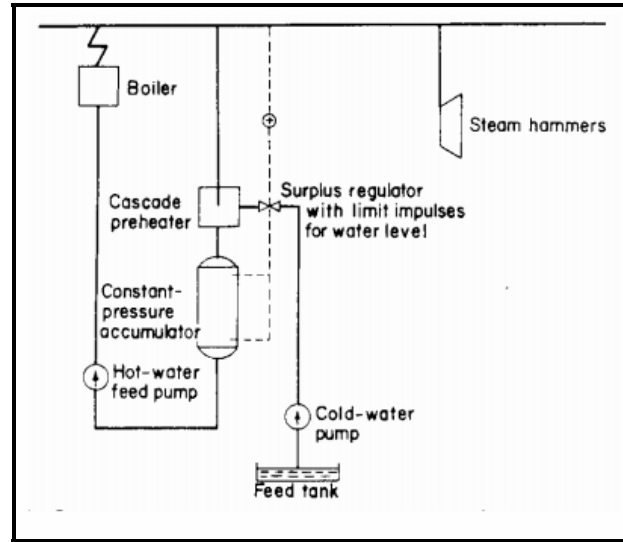
3.3. Oxygen-Steel Works

A varying pressure of diameter 2.5m and length 12m, operating in the pressure range from 5 to 18 bars was installed to recover waste heat from oxygen steel converters and assist in supplying steam to the works at a steady rate as shown in Figure 10. Without the accumulator, the steam generated from waste heat would be blown to the atmosphere and completely lost.

4. Conclusion

Based on the review on the steam accumulator application above, a radical investigation has to be carried out to study the diversities of steam accumulator in handling pressure fluctuations in oil palm mills. This is due to the fact that steam storage installations have been successfully operating today in thousands of industrial installations. Therefore, the possible effects and advantages of steam accumulator deserve to be more generally known in order to bring out the most efficient use of steam in palm oil mills.

Figure 10: Pressure drop accumulator for recovery of waste heat at oxygen steelworks
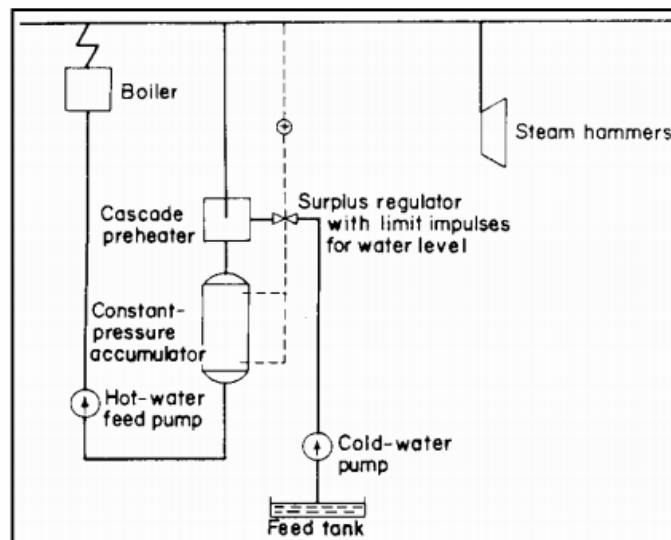
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