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Conversion of a spare steam Boiler to a steam accumulator for handling fluctuating steam demand of a dairy Industry to eliminate firing of an auxiliary boiler

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Abstract

ABC Dairy Industry is a batch processing plant that is equipped with a steam generation and distribution system. The steam demand in the process plant is rarely steady due to sudden fluctuations with steam in the application. Load cycles are short-term frequent peaks of short duration but very high instantaneous flow rates. Steam generation should be with minimum fuel consumption, at worst the result is the pressure drop and production downtime due to the instantaneous flow rate in the ultra-pasteurization process.

The paper will explain, load handling design with no production downtime with limited resources and cost-effective manner. Other objectives are the spare boiler preservation without steam generation, Handling plant loads with a single boiler and steam generation with maximum SFR (steam to fuel ratio), reducing carbon emission, and using the steam accumulator as a steam generator with minimum changes if required. This modification method is applied for the spare boiler and relevant mounting and accessories. The proposed major change is to remove the burner for safe side operation but can be reinstalled with requirements. A spare boiler consists of an economizer and with future developments heat recovery system can be applied even for the steam accumulator after analyzing the running condition of the existing economizer.

With the proposed accumulator, no of seconds that can be run without steam generation is 2 min and 13 seconds. The existing SFR is 13.6 kg/l and the expected SFR after conversion is 13.9 kg/l and the Fuel saving per month is LKR 882.35 liters. Cost saving is nearly LKR 2,57,646.00 per month and annually it will be nearly 3 million and 34.94 tCO2-e annual emission reduction from steam generation.

Key Words: *Steam Accumulator, Ultra pasteurization, Steam, Boiler*

1.0 Introduction

1.1 Background

ABC is dairy product manufacturing factory. Energy sources are mainly electrical energy and thermal energy. Generally thermal energy is obtained from furnace oil while thermal energy is use for plant processing, this may consider as main energy requirement for plant operation.

Figure 1 shows the energy consumption as the percentage of the manufacturing process and from that 29% of steam generation under thermal energy.

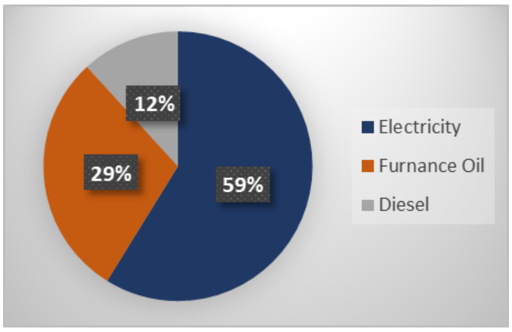

Figure 1 - Distribution of Energy Consumption

Not only an energy cost reduction opportunity, but also deliver a low carbon economy manufacturing industry has common responsibility for reduce energy consumption by optimizing the existing process.

ABC Dairy manufacturing industry, Steam system consist with steam generation, steam distribution, steam control and management and condensate management.

In the steam generation system, there are two numbers of running boilers which are named as B1(boiler 1) and B2(boiler 2), spare boiler named as B3(boiler 3). Boiler 3 is wet back, three pass fire tube boiler and with the last Inspection It was Identified as, that has been faced the surface corrosion due to long time does not use the boiler but working as spare boiler in an any emergency. With the surface corrosion it must be preserved for safe side and verified boiler working condition by NDT (Non-Destructive Test).

In the steam consuming system, steam provides mainly for process heating and CIP(Clean-in-place) process and no direct contact applications. There are two types of heat exchanger using in the system those are PHE(plate heat exchanger) and THE(Tube heat exchanger). In a heat exchanger, the steam transfers its latent heat to a process fluid.

By checking the load profile of most recent 5 months, it was identified as 1920 kg/h is the maximum instantaneous load consumption during the process as shown in figure 2.

In actual operation process as shown in Figure 2, both boilers running patterns in two colors and average load consumption is nearly 600kg/h.

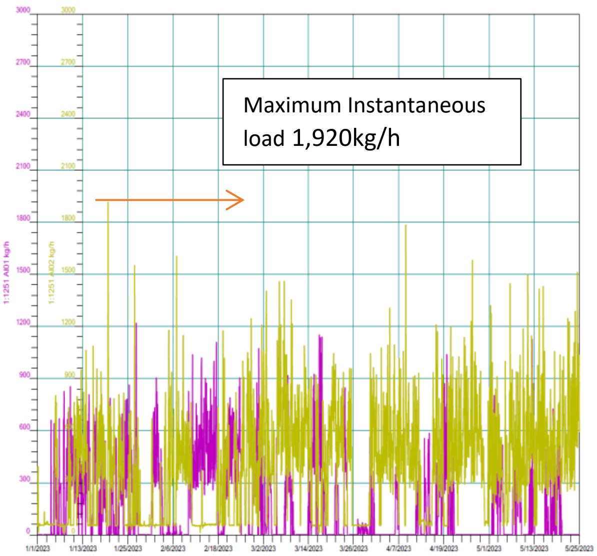

Figure 2 -Plant load variation for 5 months

Load handling is the main challenge of plant operation due to instantaneous load consumption. Even with low load conditions both boilers are at running conditions by consuming more fuels as shown in table1.

Table 1: Every 1 min boiler load handing on 5/17/2023

Time	Boiler 1(kg/h)	Boiler 2(kg/h)
7:00 AM	123.100	345.550
7:01 AM	132.100	339.300
7:02 AM	196.850	382.850
7:03 AM	239.850	351.300
7:04 AM	243.200	343.000
7:05 AM	270.900	358.800
7:06 AM	254.300	361.550
7:07 AM	274.300	287.000
7:08 AM	280.150	745.150
7:09 AM	282.350	500.400
7:10 AM	197.100	545.600
7:11 AM	127.850	331.800
7:12 AM	287.650	91.550
7:13 AM	346.900	54.550
7:14 AM	319.050	55.500
7:15 AM	253.000	76.300

1.2 Problem Statement

Thermal processing is the application of heat energy to achieve a desired effect on a food.

ABC Dairy manufacturing plant, thermal processing methods includes ultra -pasteurization process which is very critical dairy hygiene requirement and critical thermal processing method as below.

Downtime effected critical production process is 10°C Chilled milk heated up to required level.

143°C Production down point	139°C
Hot water temperature	152°C
Production (milk) flow rate	1,500 l/h
Required steam flowrate	495 kg/h
Required steam pressure	5 bar g
Steam low alarming pressure	5.5 bar g

Steam supply seems smooth way with good steam quality when subjected to a steady steam demand when boiler rating match with the steam supply but when a steam system motorized valve open quickly, a rapid steam load demand occurs, and the boiler will depressurize with insufficient steam volumes within 1 min or less.

In case of subjected process, with unavailability of steam with required pressure more than 1min with 50% of motorized valve open may cause to 4 hrs. production down time with 3 hrs. CIP and 1 hr. Sterilization process.

Further in short, peaks are effect,

1.Loss of production
2.Reduce product quality
3.Increased production times
4.Poor quality steam from the boiler
5.Low fuel efficiency
6.High maintenance cost
In this case, average steam flowrate is 900kg/h and can be supplied the steam requirement through the single boiler without instantaneous changes.[1]

1.3 Objectives

The main objective is process load handling with no production downtime and other objectives are boiler 3 preservation without steam generation, handle plant loads with single boiler and steam generation with maximum SFR and reduce carbon emission per MT value.

1.*4 Literature Review*

The purpose of the steam accumulator is to release steam when the demand is greater than the boiler's ability to supply streamflow rate at the time, and to accept steam demand is low. drastically depressurized boilers may face with low quality of steam and low water boiler cut-off. To mitigate these consequences of high steam demand in short time, we can take actions as below.[1]

1.Oversize the boilers
2.Use steam accumulator

Ultra-high temperature processing of milk is very critical operation in dairy industry processing of milk involves heating milk in a continuous process to temperature heating to 137°C-142°C for a few seconds, cooling rapidly[6]. In this case, it highlights the significance of the temperature-time profile of the UHT process and relates this to changes that occurs during processing as shown in table 2.

Table 2: Temperature profile for UHT process

Process	Standard parameters
Heating	5°C- to 75°C
Homo	75°C
Heating	90°C
Protein Denaturation	30 sec holding at 90°C
Heating	137°C-142°C
Holding	1-4 Sec
Colling	25°C-5°C

One another critical operation is load handling procedure of tubular UHT process as shown in figure 3. This is through tubular heat exchanger works by passing fluid of different temperatures through concentric tubes. The liquids usually flow in opposite direction to provide maximum cooling and heating effect.

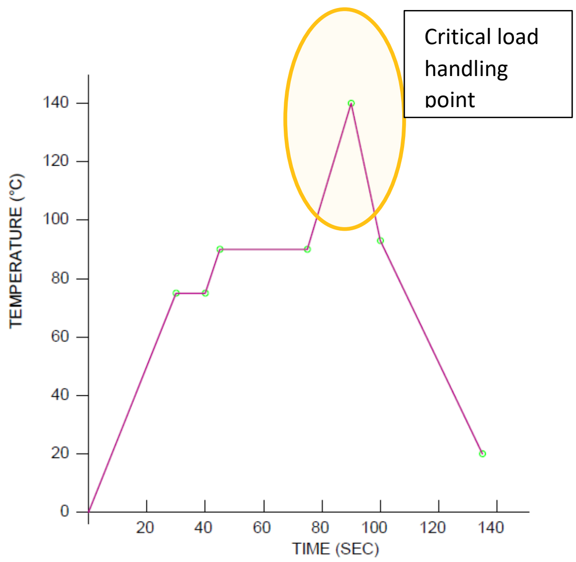

Figure 3 -Temperature graph for tubular UHT

Liquid plant UHT processing is a continuous process with heating, holding and cooling section. The process is steam based indirect method involve with plate heat exchanger. The process is irreversible if the steam pressure gets low. The total process needs to be started with 4-5 hrs. Sterilization process also critical load consuming process as shown in figure 4. product down time with additional energy consumption for CIP process and reprocessing of the same product badge. This is considerable financial loss for the dairy manufacturing Industry.[6]

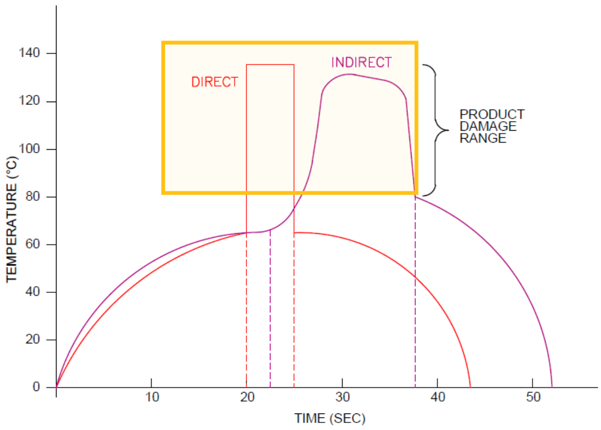

Figure 4 -Direct and Indirect Continuance Sterilization [11]

Generally, when planning a project always try to go for a low-cost solution hence one solution to this is design steam accumulator than oversize the boilers. Challenge is incorporate existing spare boiler into the steam distribution network. The paper will explain how to convert spare boiler as steam accumulator and how we can use it as stream generator if required.

Effectiveness of the steam accumulation relies on the pressure differential between steam generating plant and final process, in this case as most manufacturing process, steam is usually generated at a higher pressure than is required at the process.

At times of surplus steam generating capacity, the higher-pressure steam is discharged through feed water line into water inside the accumulator. The water takes up the latent heat from the steam thus considering it back into water. When the accumulator is required to discharge steam to a lower pressure process, steam is flashed off from the high pressure, high temperature water, thus reducing the total heat of the water content.[1]

The paper will explain how we can use existing pressure vessel as steam accumulator by considering

1. Pressure different between steam generation and plant process
2. The size of the steam demand peaks to be catered for

When we consider a new design, Steam accumulators are typically designed as a cylindrical vessel that to have the greatest possible surface area because evaporation occurs on the surface. For this these cylindrical tanks are positioned horizontally." The principle is that they operate at 50% to 90% capacity to ensure a sufficient surface area for steam quality and evaporating speed, the quality and speed increase with decreasing of tank content 50%''. Furthermore, it is necessary to ensure the possibility of discharging the condensate water. Due to heat losses with plant conditions condensate is accumulating and discharging point to behave there. The size of steam accumulator depends upon the plant load, but we can regulate it with constant flow by combining accumulator with the boiler. In this paper we will discuss about whether this existing spare boiler match with this requirement.

2.0 Steam accumulator (SA) design consideration methodology

2.1 Charging and discharging cycle

2.1.1Charging

The model accumulator partially filled with water 50%-90% full depending on the application[2]. Steam is charged beneath the surface of the water by using steam supply through the existing feed water pipe, until the entire water content is at the required pressure and temperature.

2.1.2 Discharging

As a pressure drop occurs in a steam accumulator with the stored water at saturation temperature, flash steam will be generated at the rate demanded by any load above the boiler capacity. In practice the steam accumulator volume is based on the storage required to meet a peak demand, with an allowable pressure drop, whilst still supplying clean dry steam at a suitable steam release velocity from the water surface. In this case we already have the steam accumulator and to be checked whether available pressure vessel which is suite for the plant load handling requirement.[3]

As per main design consideration mainly we have to observe the single minute plant load variation as shown in table 3 with critical load fluctuation range.

Table 3: Single minute plant load variation (25/05/2023)

Time (single min)	Plant load(kg/h)
10:00 AM	532.850
10:01 AM	627.350
10:02 AM	757.150
10:03 AM	1607.050
10:04 AM	1903.400
10:05 AM	1732.100
10:06 AM	1267.700
10:07 AM	877.750
10:08 AM	760.800
10:09 AM	717.200
10:10 AM	689.700
10:11 AM	900.750
10:12 AM	769.700
10:13 AM	929.900
10:14 AM	883.200
10:15 AM	614.800

Table 4: Every 5 seconds plant load variation (25/05/2023)

Time (every 5 second)	Plant load(kg/h)
10:02:25 AM	757.650
10:02:30 AM	824.600
10:02:35 AM	1625.850
10:02:40 AM	1724.950
10:02:45 AM	1523.300
10:02:50 AM	1531.700
10:02:55 AM	1575.150
10:03:00 AM	1607.050
10:03:05 AM	1643.400
10:03:10 AM	1712.300
10:03:15 AM	1784.400
10:03:20 AM	1712.100
10:03:25 AM	1745.950
10:03:30 AM	1756.900
10:03:35 AM	1719.900
10:03:40 AM	1705.800
10:03:45 AM	1734.750

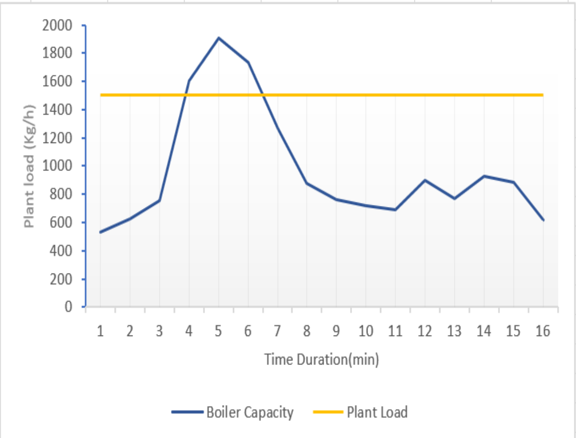

Figure 5 -plant load single minute variations

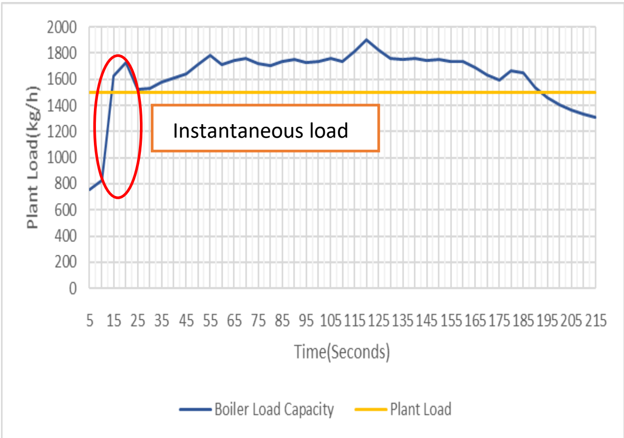

Figure 6 - 3min to 5min every 5 seconds Plant load variation

After Picked up most significant time period It has been closely monitored every 5 seconds load variation in plant operation as shown in figure 6.

This monitoring results was based on the check the load handling ability of existing boiler 3 as a steam accumulator. Flow due to steam will be stopped by solenoid valve. Feed water pumping pressure (15 bar g) is above steam pressure (10 bar g) as per the design.

2.1.3 Calculation

The steam storage capacity in an existing pressure vessel can be calculated by using below equation.SA (Steam accumulator) design pressure existing pressure vessel design pressure.

Water capacity =Boiler NWL Weight-Boiler dry Weight (from Boiler manual).

Initial data

Initial design pressure	10 bar g
Lower pressure	8 bar g
Water mass	3688 kg
Peak load requirement	1960 kg/h

From steam table:

Sensible heat at 10 bar g	781 kJ/kg
Sensible heat at 8 bar g	742 kJ/kg
Latent heat at 8 bar g	2030 kJ/kg

Steam storage capacity(kg) = X

Difference in enthalpy of water (kJ/kg) = Δh_w

Mass of water(kg) = M

Enthalpy of evaporation at the lower pressure= h_f

$$X = \frac{\Delta h_w \times M}{hf} \quad (1)$$

FS(Flash steam) generation = (781-742/2030) kJ/kg* 3688 kg

=70.85 kJ

Note that 70.85kg of flash steam will be released in the time taken for pressure drop.

Peak Load requirement = 1920 kg/h = 0.53 kgs^1

No of seconds which can be run without steam generation = 70.85kg /0.53 kgs^{-1}

= 133 seconds

= 2 min and 13 seconds

Peak load steaming requirement is 1920kg/h and we can supply steam without dropping required pressure throughout 133 seconds. Hence the combined boiler and accumulator outputs could meet maximum overload condition as per the production requirement.

2.1.4 Losses and gains

The current practice is steam generated by both boiler 1 and boiler 2. With these modifications we can supply full steam capacity by Using a single boiler.

Assume accumulator recharge hours base on plant loads by live steam	2h /day
Additional live steam requirement	3000kg/day
Expecting SFR (Considering current condition of steam generator)	13.9 kg/l
Additional fuel requirement	215. 82 liters
With current practice 2nd boiler operating hours	8 h/day
Existing SFR	13.6 kg/l
Fuel saving	882.35 liters

2.1.5 Pipe and Fittings

The pipe rework between the boiler and steam accumulator planned with minimum rearrangements with considering modifications. Figure 7 shows that proposed usage of B3 as steam accumulator with existing piping arrangement and figure 8 shows that proposed usage of B3 as steam accumulator with modified piping arrangement.

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2.1.6 Proposed Modification

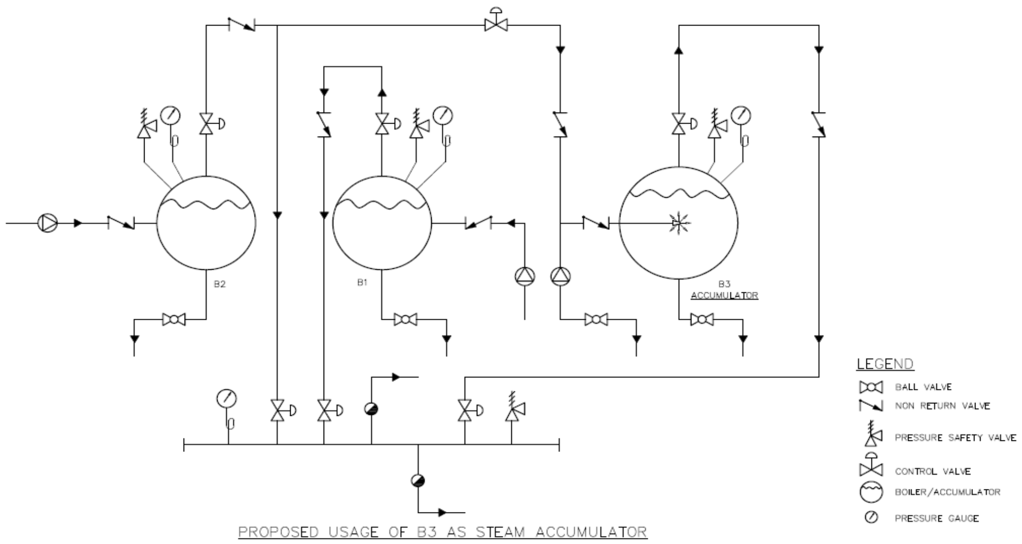

Figure 7 -Proposed usage of B3 as Steam accumulator (With Existing piping arrangement)

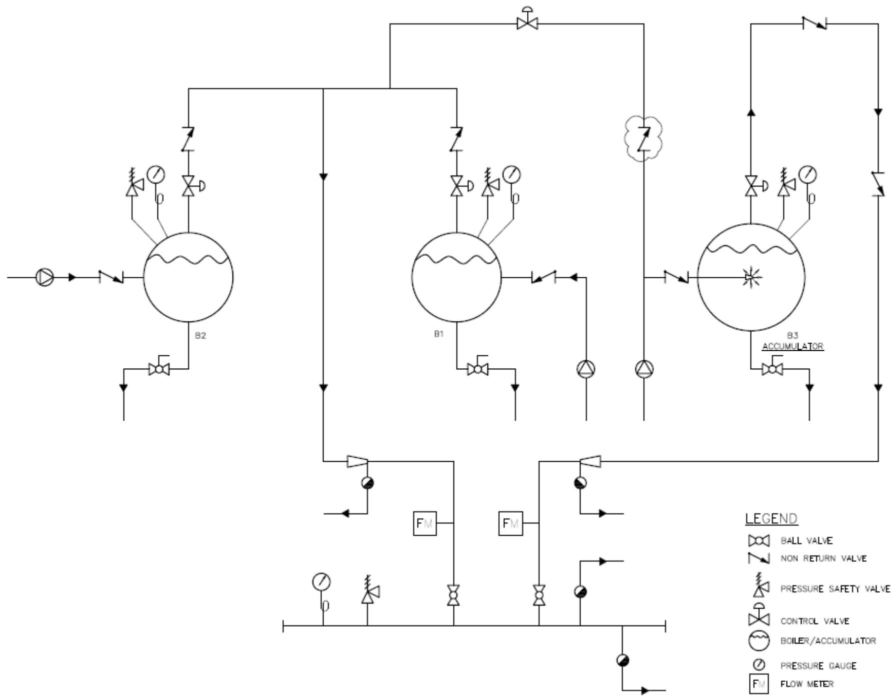

Figure 8 -Proposed usage of B3 as Steam accumulator (With modified piping arrangement)

3.0 Discussion

Steam load management is main part of the plant operation and optimizing energy is one another main part of steam generation, balancing those two requirements is vital function to assure reliability, safety of energy uses, and better economy. It is same with one another most complex and difficult tasks representing the paper by challenging the existing system to enhance the plant performance.

Before proceeding with the proposed developments, It is appropriate to go through with theoretical calculations with analysing the past data. In addition to the fundamental requirement of understanding the process, it is essential that have a study of existing P&I D s and propose existing streamline and valve rearrangement. Instead of changing the entire steam generation process here we introduced how to utilize the existing system with minor modifications, however with future perspective, it has been introduced better design in figure 8 and wherever possible we shall develop the concept with heat recovery system. Figure 9 shows typical steam injection system but here we used existing water supply system for steam injection.

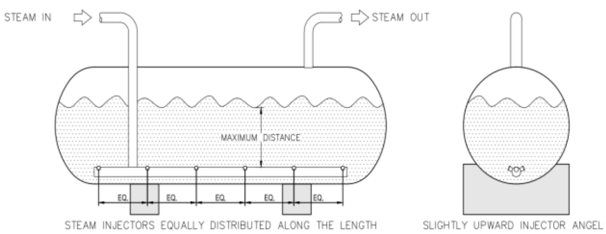

Figure 9 -Typical steam Injection system [10]

This would be satisfactory to maintain drum pressure by maintaining required temperature of water otherwise the boiler pressure may have to go down and designed system does not work with required MCR (Maximum continuous rating) and flow at one pressure would be inadequate.

With the proposed modifications boiler 3 will be converted as a steam accumulator and boiler 1 will be operate in standby condition. Steam generation will be continued with boiler 2. Boiler 3 preservation requirement has been eliminated and with the proposal load handling would be smooth than previous situation.

Further we can propose heat recovery system by using economizer as shows in figure 10 in future with more benefits.

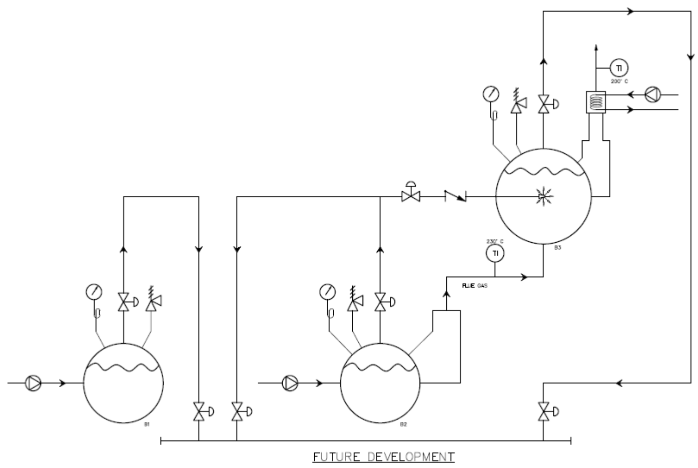

Figure 10 -Further Modification Option 2

Justifying the modification

Comparing the running conditions of two boilers only meet the peak demand, single boiler with an accumulator is cost benefits as per the calculations. Estimating high SFR with fuel saving opportunity with maximum output on a steadier load from single boiler. Expect the financial advantages of reduced maintenance on boiler plant, plant equipment's due to result of steadier boiler load and better-quality steam.

4.0 Conclusion

Steam load management of ABC Dairy manufacturing facility is very critical due to instantaneous load variations. Due to poor load management ability, there was some production downtimes has been occurred in plant history and it was a huge capital loss when considering wastage, time consumption and production rebadge process.

As per the solution, In this paper, spare boiler has been converted as steam accumulator without major changes and considering reconversion possibility as a steam generator if required. Through the analysis of the past data following conclusion can be drawn.

1.No Major changes for steam generator when converter to it as accumulator and no major changes for distribution system but few changes with valve arrangement.

2.The steam regeneration rate of the accumulator is related to the steam demand under steam flow rate and steam pressure.

3.For 1920 kg/h load requirement 2 min and 13 seconds can run without steam generation as per the mathematical analysis.

4.The steam temperature and pressure of steam accumulator, which are decreased by time, but steam flowrate stable with requirement within the define time.

5.With this modification's boiler 2 use as steam generator, Boiler 1 use as stand by boiler and boiler 3 use as steam accumulator.

6.Standby boiler also plant to connect steam accumulator charging network, hence for both boilers have steam accumulator for load handling purpose.

7.By stopping boiler 1 from continuous running condition, expected fuel saving is 882.35 l/month.

8.Main advantages is plant load handing without production downtime and additional are fuel saving, energy saving and emission reduction from this project outcomes.

5.0 Acknowledgement

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[11] Dairy college training program, ABC Manufacturing company

7.0 Abbreviations

CIP- Clean-in-place

FS-Flash Steam

NDT-Non-Destructive testing

NWL - Normal Water Level

MCR-Maximum continuous rating

PHE-Plate Heat Exchanger

SA-Steam Accumulator

SFR -Steam to Fuel ratio

THE-Tube Heat Exchanger